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FOR THE USE OF BEGINNERS.

With Illustrations.

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PREFACE.

WHILE every other branch of useful knowledge and science may be said to be overwhelmed by initiatory works for the novitiate in them, it is no slight reflection on the Naval Scientific department of this great maritime country, that neither rudimentary nor elementary works on the science of Naval Architecture, the labours of British Naval Architects, are to be found amongst the standard works of our libraries. Humiliating as this assertion may be deemed, the fact remains incontrovertible. There are, no doubt, works on Naval Architecture by the Swedish constructor Chapman, and the no less eminently talented Naval architect Clairbois; and these, by the industry of Englishmen, have been translated and made capable of adaptation to the requirements of the British Naval Architect; but these works, from the depth of mathematical knowledge required for their perusal, and from the expense attending on their purchase, are sealed sources of information to practical and demi-scientific men, and are no less the results of the gifted minds of foreigners, who have directed their energies to a subject of such paramount moment to the British Empire, as the improvement of the science of Naval Architecture. The imputation of want of energy—I will not say want of talent—remains at our door; and if this rudimentary work, on the necessary calculations to be made for a Naval Construction, should excite emulation in this branch of science,

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which is of such vast importance to England, as being the first Marine Power of the world, one end will have been obtained; and, in addition, I shall feel no small degree of pleasure in having added my mite to the general fund of useful knowledge, by placing in the hands of the young Naval Architect a Rudimentary Text-Book on Naval Construction.

J. P. P.

Woolwich,
July, 1849.

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RUDIMENTARY NAVAL ARCHITECTURE.

PART I.

The Displacement of a Floating Body considered.—Application of the Law thus determined to the Displacement of a Ship, when treated as a Floating Body.—The Calculations on the Immersed Portions of a Ship absolutely necessary to avoid Failure and Unnecessary Expense in such Costly Fabrics.

When a body floats on a fluid, it displaces as much of that fluid as is equal in size and form to the portion of the body which is immersed, and the bulk of fluid thus displaced is known to be equivalent in weight to the weight of the whole body; the measure therefore in solidity, of the portion of the body that is immersed, will give the magnitude of the fluid displaced, and the weight of this bulk of fluid will give the weight of the floating body.

It being the object of the naval constructor to ascertain with accuracy the displacement and immersion of a ship, it becomes thence necessary to measure that portion of the body of the ship which it is proposed should be immersed; to effect which, Stirling's Rules of Differentials have been employed by the Swedish constructor Chapman, and French naval architect Clairbois. Their application of these Rules cannot be too highly prized by the naval architect, giving, as they do with precision, the volume displaced, the position of the centre of gravity of that displacement, and a comparative stability of ships.

In applying the methods thus adopted by Chapman and Clairbois in detail to an example in naval construction, it will

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be the earnest endeavour in this Rudimentary Work on Naval Architecture to divest the subject of all technicalities, and to place it within the comprehension of the uninitiated in this branch of scientific knowledge; and if the garb in which the intended instruction is clothed should be thought too simple by those to whom the application of these calculations may be an every-day occurrence, it is at once admitted, that these rudiments were not written for their edification, although the careful perusal of them may, even by such proficients, be found to be not wholly without profit and utility.

After having made the novice in these matters acquainted with the ordinary modes of conducting these essential calculations on the immersed portion of a ship, a more concise method of applying the same rules will be given, which will be followed by these rules being employed under a system which will be found greatly to facilitate the labours of the naval constructor, to register and compare the forms of ships, whether mercantile or for the purposes of war, and by which the qualities of a design for any proposed ship may be developed with certainty, and the errors of a constructor be made apparent before his design is put into practice; thence avoiding the disgrace, together with the useless and vast expense which ever await on an unsystematic arrangement of important calculations, and on unscientific deductions from ill-digested and misunderstood results. It is not intended to give the mathematical demonstrations on which these rules are founded—as the knowledge required to follow such demonstrations to the desired end is beyond the assumed acquirements of the novice —the truth of these rules must be taken by such persons with faith; and to the scientific no appeal is required in favour of the ground-work of the calculations, the accuracy of Sterling's Rules having been tested by the unerring results given by mathematical research, confirmed as they have been by years of practical experience.

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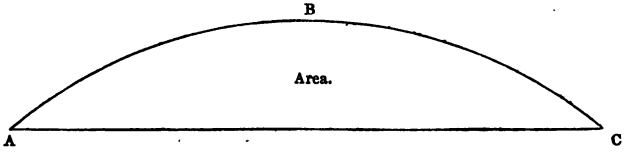
PART II.

The Application of Sterling's Rules to the Measurement of Areas, bounded by a Straight Line as a Base and a Curve Line; the first Rule requiring an odd Number of Ordinates, the second Rule that the Ordinates must be in Number a Multiple of the numeral three, with one added.

Two rules were given by Sterling for measuring the area or superficial space enclosed by a curve, and a straight line taken as a base; thus, in FIG. 1.

FIG. 1.

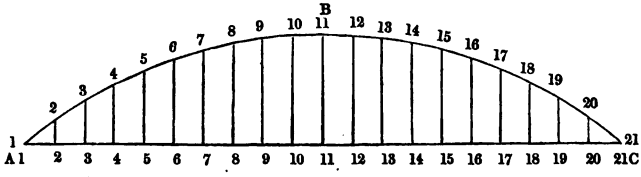


A B C is the curve line, and A C the base.

RULE THE FIRST.

If the area bounded by the curve line A B C and the straight line A C is required to be estimated, by the rule, the base A C is divided into an even number of equal parts, as in the Fig. No. 2, to give an odd number of points of division.

FIG. 2.



Where the base A C is divided into twenty equal parts, giving twenty-one points of division, and the lines 1.1, 2.2, 3.3, &c.,

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are drawn from these points at right angles or square to A C, to meet the curve A B C, these lines, 1.1, 2.2, 3.3, &c., are denominated ordinates, and the linear measurement of them, on a scale of parts, is taken and used in the following general expression of the rule.

Area $= \{A + 4\ P + 2\ Q\} \frac{r}{3}$.

Where A = sum of the first and last ordinates, or 1.1 and 21.21 of Fig. 2.

4 P = sum of the even ordinates multiplied by 4.

Or, $\{2^{nd} + 4^{th} + 6^{th} + 8^{th} + 10^{th} + 12^{th} + 14^{th} + 16^{th} + 18^{th} + 20^{th}\} \times 4$. Fig. 2.

2 Q = sum of the remaining ordinates; or,

$\{3^{rd} + 5^{th} + 7^{th} + 9^{th} + 11^{th} + 13^{th} + 15^{th} + 17^{th} + 19^{th}\} \times 2$. Fig. 2.

And r is equal to the linear measurement of the common interval between the ordinates, or one of the equal divisions of the base A C. This rule, for determining the area contained under the curve and the base, may be put under another form; for as the

Area $= \{A + 4P + 2Q\} \times \frac{r}{3}$;

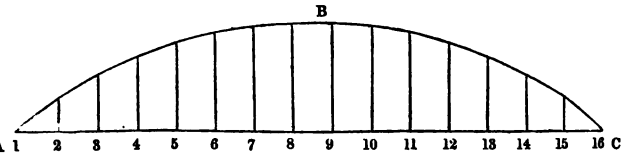
it may be transferred into

Area $= \left\{\frac{A}{2} + 2P + Q\right\} \times \frac{2r}{3}$.

The practical advantages to be derived from this modification of the general rule will appear when the methods of calculation are further developed.

Rule the Second.

Fig. 3.



If the base A C be so divided that the equal intervals are in number a multiple of the numeral 3, then the total number

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of the points of division, and consequently the ordinates to the curve, will be a multiple of the numeral 3 with one added, and the area under the curve A B C, and the base A C, can be determined by the following general expression:

$$\text{Area} = \{A + 2P + 3Q\} \times \tfrac{3r}{8}.$$

Where A = sum of the first and last ordinates, or 1 and 16. Fig. 3.

2 P = sum of the 4th, 7th, 10th, 13th, multiplied by 2, or ordinates bearing the distinction of being in position as multiples of the numeral 3, with one added. Fig. 3.

3 Q, the sum of the remaining ordinates, multiplied by 3, or of the 2nd, 3rd, 5th, 6th, 7th, 8th, 9th, 11th, 12th, 14th, and 15th, multiplied by 3. Fig. 3.

The number of equal divisions for this rule must be either 3, 6, 9, 12, or 15, &c., being multiples of the numeral 3, whence the ordinates will be in number under such divisions, multiples of the numeral 3, with one added.

This rule admits also of a modification in form, to make it more convenient of application.

$$\text{For Area} = \{A + 2P + 3Q\} \times \tfrac{3}{8}r,$$

may be transformed to

$$\text{Area} = \left\{\tfrac{A}{2} + P + 1.5\,Q\right\} \times \tfrac{3}{4}r.$$

As before advanced for the change adopted in the general expression for the first rule, the utility of this modification of the second rule will be observable when the calculations on the immersed body are proceeded with.

The rules are formed under the supposition that in the 1st rule the curve A B C, which passes through the extremities of the ordinates, is a portion of a common parabola, while in the second rule the curve is assumed to be a cubic parabola; the results to be obtained from an indiscriminate use of either of these rules, differ from each other in so trifling a degree (considered practically and not mathematically), as not to sensibly affect the deductions derived by them.

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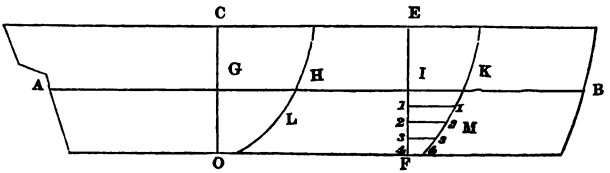
PART III.

Method of applying Sterling's Rules to ascertain the Solidity of the Bulk of Fluid displaced by the Immersed Portion of a Ship.—2nd. A Method of obtaining the same under a more Concise Mode of Application of the same Rules, by means of a Double-columned Table for the Insertion of the Measured Ordinates of the Areas.

STERLING'S Rules, when applied to the measurement of the immersed portion of a floating body, as the displacement of a ship, are used as follows.

The ship is considered as being divided longitudinally by equi-distant athwartship or transverse vertical planes, the boundaries of which planes give the external form of the vessel at the respective stations, and therefore the comparative forms of any intermediate portion of it.

FIG. 4.



If the ship be immersed to the line A B, Fig. 4, considered as the line of the proposed deepest immersion or lading, the curves H L O and K M F would give the external form of the ship at the positions G and I in that line; and the areas G H L O, I K M F contained under the curves H L O, K M F, the right lines G H, I K (the half-breadths of the plane of proposed floatation A B at the points G and I), and the right lines G O, I F, the immersed depths of the body at those points are the areas to be measured by the Rules 1 or 2; and if the areas thus obtained be represented by linear

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measurements, and are set off on lines drawn at right angles to the line A B at their respective stations, a curve bounding the representative areas would be formed, and the measurement by Sterling's Rules of the area contained under this curve, and the right line, A B, Fig. 4, or length of the ship on the load-water line, would give the sum of the areas thus represented, and thence the solid contents of the immersed portion of the ship in cubic feet of space. In accordance with this application of Sterling's Rules to measure the displacement of the ship, the usual practice is to divide the ship into equi-distant vertical and longitudinal planes, the longitudinal planes being parallel to the load-water section or horizontal section formed by the proposed deepest immersion.

To measure the areas of these planes after they have been delineated by the draughtsman, the constructor divides the depth of each of the vertical sections, or the length of each horizontal section, into such a number of equal divisions as will make either one or the other of the Rules 1 or 2 applicable. If the first rule be preferred, the equal divisions must be of an even number, so that there may be an odd number of ordinates; while the use of the second rule, to measure the area, will require the equal divisions of the base A C, Fig. 3, to be in number a multiple of the numeral 3, which will make the ordinates to be in number a multiple of the numeral 3, with one added. From the points of equal divisions in the respective sections thus determined, perpendicular ordinates are drawn to meet the curve, or the external form of the transverse planes of the body; and a table for the ordinates thus obtained, having been made as shown by Fig. 5, the measures by scale of the respective ordinates are therein inserted.

For the area I K M F, Fig. 4, the linear measurements of I K, 1.1, 2.2, 3.3, 4.4, are taken by a scale of parts, and inserted in the column marked 5, Fig. 5, the whole length A B of the load-water line being divided into 10 equal divisions, and the area I K M F being supposed as the fifth from B, the fore extreme of the load-water line. To apply the 1st

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rule 1 to the measurement of the area of No. 5 section, the ordinates are extracted from the table, Fig. 5, and operated upon as directed by the rule; viz.

$$\text{Area} = \{ A + 4P + 2Q \} \times \frac{r}{3}.$$

I K, or first,	1.1, or 2nd,	2.2, or 3rd,
4.4, or last,	3.3, or 4th,	× 2.
———	added together	or 2 Q.
added together	and × 4 = 4 P.	
= A.		

$$\text{By rule, Area} = \{ A + 4P + 2Q \} \times \frac{r}{3}.$$

Whence $\text{Area} = \{ \overline{IK} + 4.4 + 1.1 + 3.3.4 + 2.2 \times 2 \} \times \frac{r}{3}$ = area I K M F, Fig. 4; and, in a similar manner, may the several areas of the other transverse sections be determined.

When these areas have all been thus measured, they are to be summed by the same Rules; the areas themselves being considered as lines, and the result will give the solid for displacement in cubic feet. To shorten this tedious application of the formula given by Sterling's Rules, the arrangement of having double-columned tables of ordinates was introduced, as shown in Fig. 6, and for the more ready use of this enlarged table the modifications in the formula of Sterling's Rules before alluded to were adopted, that of

$$\text{Area} = \left\{ A + 4P + 2Q \right\} \times \frac{r}{3} \text{ into } \left\{ \frac{A}{2} + 2P + Q \right\} + \frac{2r}{3},$$

and that of

$$\text{Area} = \left\{ A + 2P + 3Q \right\} \times \frac{3r}{8} \text{ into } \left\{ \frac{A}{2} + P + 1.5Q \right\} \times \frac{3}{4} r,$$

as rendering the required number of figures much less, whereby accuracy of calculation is ensured and time is saved.

In using a table of ordinates constructed for this method of calculation, the linear measurement of the several ordinates of vertical section 5 and the corresponding ones of all the others would be inserted in the double columns prepared for them in the following order:—

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In the first and last lines of the enlarged table for the ordinates, distinguishable by $\frac{A}{2}$, in the left-hand column of each pair, the measurements of the first and last ordinates of the respective areas are placed, and in the right-hand column of each pair one-half of such measurements as being one-half of the first and last ordinates of each vertical section or area. In the lines distinguished by 2 P, in the left-hand column, the measurements of the even ordinates of each respective area are placed, which having been multiplied by two, the result is placed in the respective right-hand columns prepared for each vertical section; while in those lines of the table distinguished by Q, the measurements of the ordinates themselves are placed in the right-hand columns, as not requiring by the modification of the rules any operation to be used on them, before being taken into the sum forming the sub-multiple of the respective areas.

It may here with propriety be suggested, that in practice the insertion of the linear measurements of the ordinates in the table in red ink, as shown in Fig. 6, will be found useful, and that after such has been done, by the upper line of figures in the table of ordinates thus arranged, Fig. 6, being divided by two, the second line of figures being multiplied by two, and so on with the others as shown by the table, and the results thus obtained being inserted in their respective right-hand columns as before described, great facility and despatch of calculation are afforded to the constructor.

That this method will yield a correct measurement of the areas will be evident by an inspection of the terms of the general expression of Area $= \left\{ \frac{A}{2} + 2P + Q \right\} \times \frac{2r}{3}$ which are placed against the several lines of the table of ordinates. And it will be equally apparent, that the sum total of the figures inserted in the right-hand columns appropriated to each section is a sub-multiple of the area of each section, and that these results arising from the use of the form for area of $\left\{ \frac{A}{2} + 2P + Q \right\}$

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will be one-half of those that would be obtained by abstracting the ordinates from the table, Fig. 5, and using them in the expression $A + 4P + 2Q$; and therefore to complete the calculation for the areas by the rule, the first results for the areas must be multiplied by $\frac{2r}{3}$, and the last by $\frac{r}{3}$, where r is equal to the common interval or equal division of the base in linear feet; or the part of the expression for areas of $\left\{\frac{A}{2} + 2P + Q\right\}$ must be multiplied by $\frac{2r}{3}$, to make it equivalent to $\{A + 4P + 2Q\} \times \frac{r}{3}$.

The sub-multiples of the areas of the vertical sections thus determined, require to be summed together for the solid of displacement, and by considering the sub-multiples of the areas to be, as before stated, represented by lines or proportionate ordinates, Sterling's Rules, by the same table of ordinates with an additional column, may be made available to the development of the solid of displacement. For the sectional areas being represented by lines, by the first rule, ½ the the first and last areas, added to the sum of the products arising from multiplying the even ordinates or representative areas by two, together with the odd ordinates or the areas as given by the tables, and these being placed in the additional column of the table prepared for them, the sub-multiple of the solid of displacement will be given.

The operation will stand thus: sub-multiple of each of the areas $= \left\{\frac{A}{2} + 2P + Q\right\}$, or each area will be $\frac{2r}{3}$ less than the full result, and the representative lines for the areas will be diminished in that proportion; and having used these sub-multiples of the areas thus diminished in the second operation for obtaining the sub-multiple of the solid of displacement under the same rule, the results will again be $\frac{2r'}{3}$ less than the true result; therefore the sum thus determined will have to

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be multiplied by the quantity $\frac{2r}{3} \times \frac{2r'}{3}$, to give the solid required. In this expression, of $\frac{2r}{3} \times \frac{2r'}{3}$,

r = the equal distances taken in the vertical planes, to obtain the respective vertical areas;

r' = equal distances at which the vertical areas are apart on the longitudinal plane of the ship.

PART IV.

The Calculations already made by Sterling's Rule for ascertaining the Volume Immersed, applied to determine the Position of the Centre of Gravity of that Volume, or of that of the Displacement,—Position of the Centre of Gravity of a System of Bodies.—The same Reasoning applied to find the Centre of Gravity of Displacement of a Ship.—Its Application under the System of using a Double Table of Ordinates.

The displacement being thus determined, by an arrangement of an enlarged table of ordinates, the functions arising from the sub-multiples of the areas of the vertical sections being placed in Sterling's Rules to ascertain the displacement, may be used in the table of ordinates to find the distance of the centre of gravity of the immersed body from any assumed vertical plane; and also the distance that the same point—"the centre of gravity of displacement"—is in depth from the load-water or line of deepest immersion, and that from the considerations which follow:—

In a system of bodies, the centre of gravity of it is found by multiplying the magnitude or density of each body by its respective distance from the beginning of the system, and dividing the sum of such products by the sum of the magnitudes or densities. The displacement of a ship may be considered as made up of a succession of vertical immersed areas; and if it be assumed that the moments arising from multiplying the area of each section by its relative distance from an

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initial plane, may be represented by successive linear measurements, Sterling's Rules will furnish the summation of such moments; and the displacement or sum of the areas has been obtained by a similar process, from whence, by the rule for finding the centre of gravity of a system as before given, the distance of the common centre of gravity from the assumed initial plane would be ascertained, by dividing the sum of the moments of the areas by the sum of the areas or the solid of displacement.

To extend this reasoning to the enlarged table of ordinates used for the 2nd method of calculation: the sub-multiples of the respective areas, when put into Sterling's Rules to obtain the proportionate solid of displacement, are relatively changed in value to give that solid, and consequently the moments of such functions of the vertical areas will be to each other in the same ratio; and the sum of these proportionate moments, if considered as lines, can be ascertained by multiplying the functions of the areas by their relative distances from the assumed initial plane, or by the number of the equal intervals of division they are respectively from it, and afterwards, by Sterling's Rules, summing these results, forming the sum of the moments of the sub-multiples of the functions of the vertical areas: and the proportionate sub-multiple for the displacement is shown on the table; the division therefore of the former, or the sum of the proportional moments of the functions of the areas, by the proportionate sub-multiple for the displacement, will give the distance (in intervals of equal division) that the centre of gravity of the displacement is from the initial plane, which being multiplied by the value in feet of the equal intervals between the areas, will give the distance in feet from the assumed initial plane, or from the extremity of the base line of the proportional sectional areas for displacement. This reasoning will apply equally to finding the position of the centre of gravity of the body immersed, both as respects length and depth, and on the enlarged tables for construction

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given by Fig. 6, the constructor, by adopting this arrangement, will at once have under his observation the calculations *on*, and the results *of*, the most important elements of a Naval Construction.

PART V.

Method of describing a Curve of Vertical Sectional Areas.—Its Application to the Calculations required on the Immersed Portion of a Ship.—1st. To the Displacement.—Relative Capacities of the Fore and After Bodies of Immersion, denoted by the Area of Sections.—The Light Displacement or Weight of the Hull of the Vessel, obtained under the same System.—Practical Utility of it in stowing the Hold of the Vessel with Stores and Weights.—The Sectional Area measured by Sterling's Second Rule.

THE foregoing tabular system, for the application of Sterling's Rules to the calculations required on the immersed volume of a ship's bottom, led to a linear delineation of the numerical results of the tables, and thence the development of a curve of sectional areas, on a base equivalent to the length of the immersed portion of the body, or of the length at the load-water line. To effect this, the sub-multiples of the sectional areas, taken from the tables for calculation, are severally divided by such a constant number as to make their delineation convenient; then these thus further reduced sub-multiples of the areas, being set off at their respective positions on the base, formed by the length of the load-water line, a curve passed through the extreme points of these measurements, will bound an area, that to the depth used for the common divisor would form a zone, representative of the solid of displacement. The accuracy of such a representation will be easily admitted, if the former reasoning on Sterling's Rules is referred to.

To obtain the solid of displacement from this representative area, the load-water line or plane of deepest immersion is considered as being divided lengthways into two equal parts, which assumption divides the base of the curve of sectional areas also

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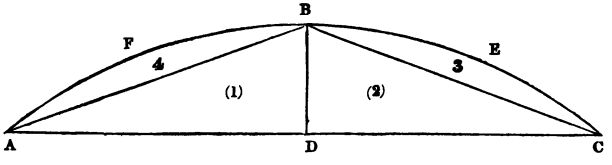
into two equal portions: the line of representative area to that medial point is then drawn to the curve, and triangles are formed on each side of it by joining the point where it meets the curve with the extremities of the base line; this arrangement divides the representative area into four parts, two triangles which are equal, viz. 1 and 2, and two other areas which are contained under the hypothenuses of these triangles and the curves of sections, or 3 and 4 of the annexed diagram.

DIAGRAM OF A CURVE OF SECTIONAL AREAS.



A B C D A = sectional area, representative of the half displacement as a zone of a given common depth.

A C equal the length of the load-water section from the fore-side of the rabbet of the stem to the aft-side of the rabbet of the post, and D the point of equal division.

B D, the representative area of half the immersed vertical section at the medial point D, joining B with the points A and C, will complete the division of the representative area A B C D A.

A B D and C B D, under such considerations, are equal triangles.

B E C B, B F A B, areas, bounded respectively by the hypothenuse A B or B C of the triangles and the curve of sectional areas; and, supposing the curves A F B and B E C to be portions of common parabolas, the solid of displacement will be in the following terms:—

The area of each of the triangles is equal to $\frac{1}{4}$ of A C × B D; hence the sum of the two = $\frac{1}{2}$ of A C × B D: the hypothenuse A B or B C = $\sqrt{\left|\frac{A C}{2}\right|^2 + B D^2}$; and the area of

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B E C B if considered as approximating to a common parabola $= \sqrt{\left|\frac{AC}{2}\right|^2 + BD^2} \times \frac{2}{3}$ of the greatest perpendicular on the hypothenuse B C.

Area of B F A B under the same assumption $= \sqrt{\left|\frac{AC}{2}\right|^2 + BD^2} \times \frac{2}{3}$ of the greatest perpendicular on the hypothenuse A B; whence the whole displacement will be expressed by $\frac{1}{2}$ A C × B D + $\sqrt{\left|\frac{AC}{2}\right|^2 + BD^2} \times \frac{2}{3}$ of the greatest perpendicular on the hypothenuse B C + $\sqrt{\left|\frac{AC}{2}\right|^2 + BD^2} \times \frac{2}{3}$ of the greatest perpendicular on the hypothenuse A B.

By a similar method, from the light draught of water, or the depth of immersion on launching the ship, the light displacement, or the weight of the hull or fabric, may be delineated and estimated; and the representative curve for it being placed relatively on the same base as that used for the representative curve for the load displacement, the area contained between the curve bounding the representative area for the load displacement, and the curve bounding the representative area for the light displacement, will be a representative area of the sum of the weights to be received on board, and point out their position to bring the ship from the light line of floatation, or the line of immersion due to the weight of the hull when completed in every respect, to that of the deepest immersion, or the proposed load-water line of the constructor—a representation that would enable the constructor to apportion the weights to be placed on board to the upward pressure of the water, and thence approximate to the stowage that would ensure the easiest movements of a ship in a sea.

By an inspection of the diagram of the curve of sectional areas, it will clearly be seen that the representative area for displacement under the division of it, into the triangles

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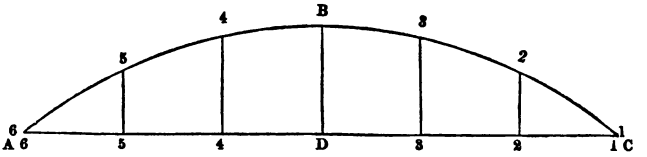
1 and 2, and parabolic portions of the area 3 and 4, will point out the relative capacities of the displacement, under the fore and after half-lengths of the base or load-water line; for, by construction, the triangles A B D and C B D are equal, and therefore the comparative values of the areas B E C B and B F A B, or of $\sqrt{\left|\frac{AC}{2}\right|^2 + BD^2} \times \frac{2}{3}$ of the greatest perpendicular on the hypothenuse B C, compared with $\sqrt{\left(\frac{AC}{2}\right)^2 + BD^2} \times \frac{2}{3}$ of the greatest perpendicular on the hypothenuse A B, or of the relative values of the greatest perpendiculars on the hypothenuses B C and A B, will give the relative capacities of the fore and after portions of the immersed body or the displacement.

The representative area A B C D A, Fig. 7, admits also of a measurement by the 2nd Rule given by Sterling.

Let B D, as before, be the representative area at the middle point.

FIG 7.



Divide A D or D C into three equal portions, then the equal divisions being a multiple of 3, the 2nd Rule is applicable to measure the areas A B D A or B C D B;

for area A B D A $= \left\{6.6 + BD + 2 \times 0 + 3\overline{\{4.4 + 5.5\}}\right\}\frac{3r}{8}$,
6.6 = 0

$= \left\{BD + 3.\{4.4 + 5.5\}\right\}\frac{DC}{8}$;

and area B C D B $= \left\{\overline{1.1 + BD} + 2 \times 0 + 3 \times \{2.2 + 3.3\}\right\}\frac{3r}{8}$,

where 11 = 0 $= \left\{BD + 3 \times \overline{\{2.2 + 3.3\}}\right\}\ \frac{AD}{8}$;

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and the displacement $= \left\{ BD + 3.\{4.4 + 5.5\} \right\} \frac{DC}{8} +$ $\left\{ BD + 3.\{2.2 + 3.3\} \right\} \times \frac{AD}{8} \times$ by the constant divisor of the areas, or the depth of the zone in feet.

The rules given by Sterling for the measurement of the immersed portion of the body of a ship, having been theoretically stated, the practical application of them will be given on the construction—drawing of a yacht of thirty-six tons. The system being the same for large or small vessels, want of space in this small work must be the accepted plea for the latter having been chosen, premising that the following considerations are necessary preparatory to the formation of a construction, or of a comparison of the elements of ships already built.

PART VI.

Preliminary Remarks previous to the Application of the Rules for Calculation to the Construction-draught of a Yacht of 36 Tons Admeasurement, old tonnage.—The Immersed Part of a Vessel considered as a Portion of the Parallelopipodon formed by the Dimensions of Length, Breadth, and Depth.—Relative Capacities of the two Bodies, or Fore and After Bodies, under the Half-lengths of the Load-water Line.—Example of Bad Construction in this Element.—Man-of-War Brigs of 1833.—The Accuracy of the Stowage of the Hold ensured by the Delineation of the Curves of Sectional Areas for Light and Load Immersions.—The Relative Capacities of the two Bodies under the same Displacement affect the Form Forward and Aft.

THE immersed part of a ship, being a portion of the parallelopipodon formed by the three dimensions;—length on the load-water line, from the fore-side of the rabbet of the stem to the aft-side of the rabbet of the stern post; extreme breadth in midships of the load-water section; and the depth of immersion in midships from the lower edge of the rabbet of the keel;—it would seem that the first step towards the reduction

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of the parallelopipodon, or oblong, into the required form, would be to find what portion of it would be of the same contents as the proposed displacement of the ship—a knowledge of which would enable the constructor, by a comparison of the result with a similar element of an approved ship, to determine whether the principal dimensions assumed would (under the form intended) give an immersed body equal to carrying the proposed weights or lading.

The relative capacities of the immersed bodies contained under the fore and after lengths of the load-water line must next be fixed, and the constructor in this very important element of a construction will find little to guide him from the results of past experience and practice. From deductions on approved ships of rival constructors it will be developed, that in this essential element, "the relative difference between the two bodies," they vary from 1 to 13 per cent. on the whole displacement, and that in the system adopted by Sir William Symonds, the late Surveyor of the British Navy, where similarity of form was insisted upon, the range in this particular was from 3 to 13 per cent. on the whole displacement or volume immersed.

The relative capacities of the fore and after bodies of immersion under the proposed load-water line would seem at the first glance of the subject to be a fixed and determinate quantity, as being a conclusion easily arrived at from a knowledge of the proportions due to the superincumbent weights—under such a consideration the weight of the anchors, bowsprit, and foremast would necessarily be supposed to require an excess in the body immersed under the fore half-length of the load-water line over that immersed under the after half-length of the same element.

In a ship the necessary arrangement of the weights, to preserve the proposed relative immersion of the extremes or the intended draught of water, would be pointed out by a delineated curve of sectional areas, described as before directed; but a want of that system, or of some other, has often caused an

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error in the actual draught of water, and that under a great relative excess of the volumes of displacement in the fore and after portions of the immersed body.

EXAMPLE.

The Men-of-war Brigs built in the year 1833 to a construction-draught of water of 12 ft. 9 in. forward, 14 ft. 4 in. abaft, giving 1 ft. 7 in. difference, had under such a construction a difference of displacement between the immersed bodies under the fore and after half-lengths of the load-water line that was equivalent to 10·4 tons for every 100 tons of the vessel's total displacement or weight; but these ships, when stowed and equipped for sea, came to the load-draught of water of 14 ft. 2 in. forward, 14 ft. 3 in. aft.—difference 1 in. or an immersion of the fore extreme of 18 in. more than was intended by the constructor: the reason of this practical departure from the proposed line of floatation of the constructor was, that the internal space or hold of the ship necessarily followed the external form, giving a hold proportionate to the displacement contained under the several portions of the body, but an injudicious disposal of the stores (in placing the weights too far forward) made them more than equivalent to the upward pressure of the water at the respective portions of the proposed immersion of the body, and thence arose the error or excess in the fore immersion by giving a greater draught of water than was designed. The stowage of a ship's hold, under a reference to the representative area for the displacement, contained between the curves of sectional areas developed for the light and load displacements, would prevent similar errors under any extent to which the relative capacity of the two bodies might be carried. This relative capacity of the two bodies will affect the form of the vessel's extremes, giving a short or long bow, a clear or full run to the rudder; for the whole displacement *being a fixed quantity, if the portion of it under the fore half-length of the load-water line be increased,* it must be followed, *by a proportionate diminution of the portion of the displacement under*

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the after half-length of the load-water line, so that the total volume of the displacement may remain the same, which arrangement will give a proportionately full bow and clean run, and vice versâ.

PART VII.

Curve of Sectional Areas, applicable to the Comparison of the Relative Qualities of Ships of the same Rate, will give a Scale for Tonnage of Displacement under any Immersion.—Method of forming the Scale of Displacement.

THE curve of sectional areas under the foregoing considerations is also applicable to a comparison of the relative qualities of ships of the same rate, by showing at one view the distribution of the volume of displacement in each ship, under the draught of water which has been found on trial to give the greatest velocity, based on which, deductions may be made from the relative capacities of the bodies pointed out by the sectional curves, that will serve to guide the naval constructor in future constructions.

The curve of sectional areas is also available for forming a scale to measure the amount of displacement of a ship to any assumed or given draught of water. To effect this, on the sheer draught or longitudinal plan of the ship between the load-water line, or that of deepest immersion, and the line denoting the upper edge of the rabbet of the keel, drawing intermediate lines parallel to the load-water line as denoting lines of intermediate immersion between the keel and load-water line—these lines may be placed equidistant from each other, but they are not necessarily required to be so. Find the curve of sectional areas, due to each immersion of the ship denoted by these lines, and measure the areas bounded respectively by these curves, in the manner as before directed for the load displacement—these results will give the magni-

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tudes of the immersed portions of the body in cubic feet, which being divided by 35, the mean of the number of cubic feet of salt or fresh water that are equivalent to a ton in weight will give their respective weights in tons.

Assume a line of scale for depth, or mean draught of water, the lower part of which is to be considered the underside of the false keel of the ship, and set off on this line, by means of a scale of parts, the depths of the immersions at the middle section of the longitudinal plan; draw lines (at the points thus obtained) perpendicular to this assumed line for depth or draught of water, and having determined a scale to denote the tons, set off on each line by this scale the tons ascertained by the curves of sectional areas to be due to the respective immersions of the body, then a curve passed through these points will be one on which the weights in tons due to the intermediate immersions of the body may be ascertained, or the displacement of a ship to the mean of a given draught may be found by setting up the mean depth on the scale, showing the draught of water—transferring that depth to the curve for tonnage, and then carrying the point thus obtained on the curve for tonnage to the scale of tons, which will give the number of tons of displacement to that depth of immersion or draught of water.

PART VIII.

Description of Fig. 8, or of the several Plans to be delineated by the Draughtsman, previous to the Commencement of the Calculations.

Sheer Plan.—A projection of the form of the vessel on a longitudinal and vertical plane, assumed to pass through the middle of the ship, and on which the position of any point in her may be fixed with respect to height and length.

Half-breadth Plan.—The form of the vessel projected o

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to a longitudinal and horizontal plane, assumed to pass through the extreme length of ship, and on which the position of any point in the ship may be fixed for length and breadth.

Body Plan.—The forms of the vertical and athwartship sections of the ship, projected on to a vertical and athwartship plane, assumed to pass through the largest athwartship and vertical section of her, and on which plan the position of any point in the ship may be fixed for height and breadth.

These plans conjointly will determine every possible point required; for, by inspection it will be found—

That the sheer and half-breadth plans have one dimension common to both, *viz.*:	Length.
Half-breadth and body plane . .	Breadth.
Sheer and body plane . .	Height.
For sheer plan gives length and height .	of the same point.
Half-breadth plan gives length and breadth .	
Body plan gives breadth and height .	

Which dimensions form the co-ordinates for any point in the solid, and must determine the position of it.

The point *c* in the load-water section A B, of Fig. 8, has for its co-ordinates to fix its position,

The Length, 1.5 of the half-breadth plan.
Height, 5.*c* of the sheer plan,
And the breadth, 1.*c* of the body plan of section.

And the same for any other point of the solid or of the ship.

In the sheer plan, Fig. 8, A B represents the line of deepest immersion, *a a*, *b b*, *c c*, *d d*, lines drawn parallel to that line at a distance of 9 feet, making with AB an odd number of ordinates for the use of the first general rule for the area, where area = $\{A + 4P + 2Q\} \times \frac{r}{3}$, and A = the sum of the first and last ordinates.

P = the sum of the even ordinates, as 2, 4.

Q = the sum of the odd ordinates, as 3, &c.

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The line A B, or length of the load-water line, is bisected at C, and A C, C B are thence equal; C being the middle point of the load-water line, the spaces B C, A C, are again divided into four equal divisions, giving five ordinates for each space, at a distance apart of 5·5 ft.

This arrangement will give the immersed body of the vessel, as being divided into two parts under an equal division of the load-water line, and an odd number of ordinates in each section of the body for the application of the first general rule given for finding the areas of the vertical sections and thence the displacement.

The half-breadth plan delineates the form of the body immersed for length and breadth, the line A B of the sheer plan being represented in the half-breadth plan by the line marked A B, and *a a*, *b b*, *c c*, *d d*, of the sheer plan by the lines similarly distinguished in the half-breadth plan.

The body plan gives the form of the body in the depth, the lines distinguished 5.5 in the sheer and half-breadth plans being in the body plan developed by the curve 5.5.5, giving the external form of the ship at the section 5.5, the same reasoning applies to the other divisions of the load-water line A B.

PART IX.

Application of Sterling's Rules to the Calculations required for the Construction Drawing of a Yacht of 36 tons, Old Measurement.—Fig. 8. 1st, Usual Mode of Calculating the Displacement by Vertical and Horizontal Sections.

FIG. 5.

5

				I K				
				1.1				
				2.2				
				3.3				
				4.4				

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TABLE OF ORDINATES FOR YACHT OF 36 TONS.

Distinguishing No. of the Sections.	1	2	3	4	(5)	6	7	8	9	
1′ A	·4	3·0	5·0	6·0	6·3	6·1	5·4	3·7	·4	r = equal to the distance between the ordinates used for the vertical section = ·92 ft.
2′ P	·35	2·4	4·2	5·6	5·6	5·5	4·4	2·6	·35	
3′ Q	·3	1·7	3·2	4·4	5·0	4·6	3·4	1·7	·3	r' = equal to the distance between the ordinates used for the horizontal sections = 5·5 ft.
4′ P	·25	1·0	2·2	3·2	3·8	3·4	2·4	1·1	·25	
5′ A	·2	·4	1·3	2·0	2·4	2·0	1·4	·6	·2	

From this table the following application of Sterling's rule, No. 1, is usually made to obtain the volume of displacement to the draught of water shown on the drawing as the load-water line or line of proposed deepest immersion, designated on Fig. 8, Plate A, as A B.

General terms of the rule:—

$$\text{Area} = \left\{ A + 4P + 2Q \right\} \times \frac{r}{3}$$

To find ½ the area of Vertical Section 1, Fore Body:—

A = sum of the first and last ·4 + ·2 = ·6 = A

4 P = four times the sum of the even ordinates, or of (2) and (4) . . . ·35 + ·25 = ·60 = P; ·60 × 4 = 2·4 = 4 P

2 Q = twice the sum of the odd ordinates, or of (3) ·3 = Q; ·3 × 2 = ·60 = 2 Q

Whence the area, which is equal to

$$\left\{ A + 4P + 2Q \right\} \times \frac{r}{3} =$$

$$\left\{ ·6 + 2·4 + ·6 \right\} \times \frac{·92}{3}$$

$$3·6 \times \frac{·92}{3} = 1·2 \times ·92 = 1·104 = \text{½ area of Section 1.}$$

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Which sum is half the area of the Section 1, and is kept in that form of the half-measurement for the convenience of calculation.

Fore Body.

Vertical Section 2.

3·0	2·4	1·7
·4	1·0	2
3·4 = A	3·4 = P	3·4 = 2 Q
	4	
	13·6 = 4 P	
	3·4 = A	
	3·4 = 2 Q	
	20·4 = A + 4 P + 2 Q	
	·92 = r	
	408	
	1836	
	3)18·768	
	6·256 = ½ area of Section 2.	

Vertical Section 3.

5·0	4·2	3·2
1·3	2·2	2
6·3 = A	6·4 = P	6·4 = 2 Q
	4	
	25·6 = 4 P	
	6·3 = A	
	6·4 = 2 Q	
	38·3 = A + 4 P + 2 Q	
	·92 = r	
	766	
	3447	
	3)35·236	
	11·745 = $\left\{A + 4P + 2Q\right\} \times \frac{r}{3}$ = ½ area of Section 3.	

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Vertical Section 4.

6·0	5·6	4·4
2·0	3·2	2
8·0 = A	8·8 = P	8·8 = 2 Q
	4	
	35·2 = 4 P	
	8·0 = A	
	8·8 = 2 Q	
	52·0 = A + 4 P + 2 Q	
	·92 = r	
	1040	
	4680	
	3)47·840	
	15·946 = $\left\{ A + 4P + 2Q \right\} \times \frac{r}{3}$ = $\left\{$ ½ area of Section 4.	

Vertical Section 5.

6·3	5·6	5·0
2·4	3·8	2
8·7 = A	9·4 = P	10·0 = 2 Q
	4	
	37·6 = 4 P	
	8·7 = A	
	10·0 = 2 Q	
	56·3 = $\left\{ A + 4P + 2Q \right\}$	
	·92 = r	
	1126	
	5067	
	3)51·796	
	17·265 = $\left\{ A + 4P + 2Q \right\} \times \frac{r}{3}$ = $\left\{$ ½ area of Section 5.	

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Half areas of Vertical Sections, 1, 2, 3, 4, and 5.

No.	1	1·104 ft.
	2	6·256
	3	11·745
	4	15·946
	5	17·265

Displacement of the body under the fore half-length of the load-water line by the vertical sections, or the summation of the vertical areas, 1, 2, 3, 4, and 5, by the formula for the solid, as being equal to

$$\left\{A' + 4P' + 2Q'\right\} \times \frac{\delta'}{3}$$

where A' = sum of 1st and 5th areas.
P' = „ 2nd and 4th areas.
Q' = „ 3rd area.

And δ' = distance between the vertical sections, or 5·5 ft.

1. .. 1·104
5. .. 17·265

18·369 = A′

2. .. 6·256
4. .. 15·946

22·202 = P′
4

88·808 = 4 P′
18·369 = A′
23·490 = 2 Q′

130·667 = A′ + 4 P′ + 2 Q′
5·5 = δ′

653335
653335

3)718·6685

239·556 = A′ + 4 P′ + 2 Q′ × $\frac{\delta'}{3}$ = cubic feet of space in half fore-body.
2

479·112 = cubic feet of space in fore body.

3. .. 11·745 = Q′
2

23·490 = 2 Q′

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Displacement of the body immersed under the after half-length of the load-water line by the vertical areas 5, 6, 7, 8, and 9 of the table of ordinates.

Vertical Section 6.

5, as Fore Body.			
17·265	6·1	5·5	4·6 = Q
	2·0	3·4	2
	8·1 = A	8·9 = P	9·2 = 2 Q
		4	
		35·6 = 4 P	
		8·1 = A	
		9·2 = 2 Q	
		52·9 = A + 4 P + 2 Q	
		·92 = r	
		1058	
		4761	
		3)48·668	
		16·222 = $\overline{A + 4P + 2Q} \times \frac{r}{3}$ = { ½ area of Section 6.	

Vertical Section 7.

5·4	4·4	3·4 = Q
1·4	2·4	2
6·8 = A	6·8 = P	6·8 = 2 Q
	4	
	27·2 = 4 P	
	6·8 = 2 Q	
	6·8 = A	
	40·8 = A + 4 P + 2 Q	
	·92 = r	
	816	
	3672	
	3)37·536	
	12·512 = $\overline{A + 4P + 2Q} \times \frac{r}{3}$ = { ½ area of Section 7.	

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Vertical Section 8.

3·7	2·6	1·7 = Q
·6	1·1	2
4·3 = A	3·7 = P	3·4 = Q
	4	
	14·8 = 4 P	
	4·3 = A	
	3·4 = 2 Q	
	22·5 = A + 4 P + 2 Q	
	·92 = r	
	450	
	2025	
	3)20·700	
	6·9 = $\overline{\text{A + 4 P + 2 Q}} \times \frac{r}{3}$ = ½ area of Section 8.	

Vertical Section 9.

·4	·35	·3 = Q
·2	·25	2
·6 = A	·60 = P	·6 = 2 Q
	4	
	2·4 = 4 P	
	·6 = A	
	·6 = 2 Q	
	3·6 = A + 4 P + 2 Q	
	·92 = r	
	72	
	324	
	3)3·312	
	1·104 = $\overline{\text{A + 4 P + 2 Q}} \times \frac{r}{3}$ = ½ area of Section 9.	

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Half areas of the vertical sections 5, 6, 7, 8, and 9.

Sections.	Areas.
5. . . .	17·265
6. . . .	16·22
7. . . .	12·512
8. . . .	6·9
9. . . .	1·104

Displacement of the after body under the after half-length of the load-water line by the vertical sections or the summation of the immersed areas of the vertical sections 5, 6, 7, 8, and 9 by the formula for the solid as being equal to

$$\overline{A' + 4P' + 2Q'} \times \frac{r'}{3}$$

where A' = sum of the 5th and 9th areas.
P' = „ 6th and 8th areas.
Q' = „ 7th area.

and r' = the distance between the vertical sections, or 5·5 ft.

5. .. 17·265
9. .. 1·104
18·369 = A′

6... 16·22
8... 6·900
23·120 = P′
4
92·480 = 4P′

7. .. 12·512 = Q′
2
25·024 = 2Q′

25·024 = 2Q′
18·369 = A′
135·873 = A′ + 4P′ + 2Q′
5·5 = r
679·365
67·936
3)747·3015
249·1005 = $\overline{A' + 4P' + 2Q'} \times \frac{r'}{3}$ =
2 Cubic ft. in ½ after body
498·2010 After body in cubic ft. of space.

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Displacement of Fore Body by Horizontal Sections.

Horizontal Section 1′.

0·4	6·0	5·0 = Q
6·3	3·0	2
6·7 = A′	9·0 = P	10·0 = Q
	4	
	36·00 = 4 P	
	10·00 = 2 Q	
	6·70 = A	
	52·70 = A + 4 P + 2 Q	
	5·5 = r	
	2635	
	2635	
	3)289·85	
	96·61 A + 4 P + 2 Q × $\frac{r}{3}$ = { ⅓ area of Section 1′.	

Horizontal Section 2′.

·35	5·7	4·2 = Q
5·60	2·4	2
5·95 = A	8·1 = P	8·4 = 2 Q
	4	
	32·4 = 4 P	
	8·4 = 2 Q	
	5·95 = A	
	46·75 = A + 4 P + 2 Q	
	5·5 = r	
	23375	
	23375	
	3)257·125	
	85·708 = {A + 4P + 2Q} × $\frac{r}{3}$ = { ⅓ area of Section 2.′	

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Horizontal Section 3′.

·3	4·4	3·2 = Q
5·0	1·7	2
5·3 = A	6·1 = P	6·4 = 2 Q
	4	
	24·4 = 4 P	
	5·3 = A	
	6·4 = 2 Q	
	36·1 = A + 4 P + 2 Q	
	5·5 = r	
	1805	
	1805	
	3)198·55	
	66·18 = A + 4 P + 2 Q × $\frac{r}{3}$ = ⅓ area of Section 3′.	

Horizontal Section 4′.

·25	3·2	2·2 = Q
3·8	1·0	2
4·05 = A	4·2 = P	4·4 = 2 Q
	4	
	16·8 = 4 P	
	4·05 = A	
	4·40 = 2Q	
	25·25 = A + 4 P × 2 Q	
	5·5 = r	
	12625	
	12625	
	3)138·875	
	46·291 = A + 4 P + 2 Q × $\frac{r}{3}$ = { ⅓ area of Section 4′.	

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Horizontal Section 5′.

·2	2·0	1·3 = Q
2·4	·4	2
2·6 = A	2·4 = P	2·6 = 2 Q
	4	
	9·6 = 4 P	
	2·6 = A	
	2·6 = 2 Q	
	14·8 = A + 4 P + 2 Q	
	5·5 = r	
	740	
	740	
	3)81·40	
	27·13 = $\left\{ A + 4P + 2Q \right\} \times \frac{r}{3}$ = ⅓ area of Section 5′.	

Displacement of the fore body under the fore half-length of the load-water line by horizontal sections, or the summation of the horizontal sections of the fore body 1′, 2′, 3′, 4′, and 5′, by the formula for the solid, as being equal to

$$\left\{ A' + 4P' + 2Q' \right\} + \frac{r}{3};$$

where
A′ = sum of the 1′st and 5′th areas:
P′ = „ „ „ 2′nd and 4′th areas;
Q′ = „ „ „ 3′rd area;

and r = the distance between the horizontal sections or ·92 ft.,

Half areas of the Horizontal Sections 1′, 2′, 3′, 4′, and 5′.

1′ = 96·61.
2′ = 85·708.
3′ = 66·18.
4′ = 46·29.
5′ = 27·13.

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Areas.	Areas.	Areas.
1′... 96·61	2′... 85·708	3′... 66·18 = Q′
5′... 27·13	4′... 46·290	2
123·74 = A′	131·998 = P′	132·36 = 2 Q′
	4	
	527·992 = 4 P′	
	123·740 = A′	
	132·360 = 2 Q′	
	784·092 = A′ + 4 P′ + 2 Q′	
	·92 = r	
	1568184	
	7056828	
	3)721·36464	
	240·45 = $\left\{ A' + 4P' + 2Q' \right\} \times \frac{r}{3}$ = cubic ft. in ½ fore body.	
	2	
	480·90 = fore body by horizontal sections in cubic feet of space.	

Displacement, by Horizontal Sections of the body immersed under the after half-length of the load-water line, or by the horizontal areas 1′, 2′, 3′, 4′, and 5′, of the table of ordinates.

Calculated areas of 1′, 2′, 3′, 4′, and 5′.

Section 1′ After Body.

6·3	6·1	5.4 = Q
·4	3·7	2
6·7 = A	9·8 = P	10·8 = 2 Q
	4	
	39·2 = 4 P	
	10·8 = 2 Q	
	6·7 = A	
	56·7 = A + 4 P + 2 Q	
	5·5 = r	
	2835	
	2835	
	3)311·85	
	103·95 = $\overline{A + 4P + 2Q} \times \frac{r'}{3}$ = { ½ area of Section 1′.	

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Section 2′ After Body.

5·6	5·5	4·4 = Q
·35	2·6	2
5·95 = A	8·1 = P	8·8 = 2 Q
	4	
	32·40 = 4 P	
	5·95 = A	
	8·80 = 2 Q	
	47·15 = A + 4 P + 2 Q	
	5·5 = r'	
	23575	
	23575	
	3)259·325	
	86·441 = $\overline{\text{A + 4 P + 2 Q}} \times \frac{r'}{3}$ = { ⅓ area of Section 2′.	

Section 3′ After Body.

5·0	4·6	3·4 = Q
·3	1·7	2
5·3 = A	6·3 = P	6·8 = 2 Q
	4	
	25·2 = 4 P	
	5·3 = A	
	6·8 = 2 Q	
	37·3 = A + 4 P + 2 Q	
	5·5 = r	
	1865	
	1865	
	3)205·15	
	68·38 = A + 4P + 2Q × $\frac{r'}{3}$ = { ⅓ area of Section 3′.	

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Section 4′ After Body.

3·8
·25
4·05 = A

3·4
1·1
4·5 = P
4
18·00 = 4 P
4·05 = A
4·80 = 2 Q
26·85 = A + 4 P + 2 Q
5·5 = r′
13425
13425
3)147·675
49·225 = $\overline{\text{A + 4 P + 2 Q}} \times \frac{r'}{3}$ = { ½ area of Section 4′.

2·4 = Q
2
4·8 = 2 Q

Section 5′ After Body.

2·4
·2
2·6 = A

2·0
·6
2·6 = P
4
10·4 = 4 P
2·8 = 2 Q
2·6 = A
15·8 = A + 4 P + 2 Q
5·5 = r′
790
790
3)86·90
28·96 = {A + 4 P + 2 Q} × $\frac{r'}{3}$ = { ½ area of Section 5′.

1·4 = Q
2
2·8 = 2 Q

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Displacement by horizontal sections of the after body under the after half-length of the load-water line, or the summation of the horizontal sections of the after body, 1′, 2′, 3′, 4′, and 5′, by the formula of the solid, as being equal to

$$\left\{ A' + 4P' + 2Q' \right\} \times \frac{r'}{3}.$$

Half areas of the After Horizontal Sections,

1′, 2′, 3′, 4′, and 5′.

Sections.	Areas.
1′ . . .	103·95.
2′ . . .	86·44.
3′ . . .	68·38.
4′ . . .	49·22.
5′ . . .	28·96.

Areas.	Areas.	Areas.
1′ . . 103·95	2′ . . 86·44	3′ . . 68·38 = Q′
5′ . . 28·96	4′ . . 49·22	2
132·91 = A′	135·66 = P′	136·76 = 2 Q′
	4	
	542·64 = 4 P′	
	132·91 = A′	
	136·76 = 2 Q′	
	812·31 = A′ + 4 P′ + 2 Q′	
	·92 = r	
	162462	
	731079	
	3)747·3252	
	249·1084 = $\left\{ A' + 4P' + 2Q \right\} \times \frac{r}{3}$ = cubic feet in half-after body by horizontal sections.	
	2	
	498·2168 = After body by horizontal sections in cubic feet of space.	

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Displacement.

By Vertical Sections.	Cubic Ft.	By Horizontal Sections.	Cubic Ft.
Fore body (p. 29)	479·11	Fore body (p. 36)	480·900
After body (p. 32)	498·20	After body (p. 39)	498·216
Sum	977·30	Sum	979·116
Half	488·65	Half	489·558

	Cubic Ft.
By Horizontal Sections . .	979·116
By Vertical Sections . . .	977·300
Difference . . .	1·816 cubic feet.

Cubic Ft.
979·49 = capacity or displacement in cubic feet of space.

The mean weight of salt and fresh water gives 35 cubic feet of space when filled with water, to be equivalent to a ton avoirdupois; thence the displacement in cubic feet of space being divided by 35 will give the weight of the volume displaced in tons avoirdupois; or 979·49 being divided by 35 gives

5)979·49

7)195·898

27·985 Tons, the weight of the calculated immersed body in tons.

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PART X.

By the usual Method.—Area of Midship or greatest Transverse Section.—Area of the Load-water Line, or Area of the assumed Plane of Deepest Immersion.—Capacity to the Inch at that Immersion in Cubic Feet, and Tons of 35 Cubic Feet of Space.—Longitudinal Distance of the Centre of Gravity of Displacement from Section 1, considered as the Initial Plane.—Distance the Centre of Gravity is below the Load-water Line, or Line of assumed Deepest Immersion.—Distance of the Centre of Gravity of the Load-water Section from the Section 1 of Fig. 8.

Area of the Midship Section, or of the Greatest Transverse Section of Fig. 8.

Section at 5.

1.1. .. 6·3	2.2. .. 6·0	3.3. .. 4·8 = Q
5.5. .. ·2	4.4. .. 2·3	·2
6·5 = A	8·3 = P	9·6 = 2 Q
	4	
	33·2 = 4 P	
	6·5 = A	
	9·6 = 2 Q	
	49·3 = A + 4 P + 2 Q	
	1·25 = $\frac{r}{3}$ where r = the depth, from 1 to 5, divided by 4 = 5 ft. by 4 = 1·25 ft.	
	2465	
	986	
	493	
	3)61·625	
	20·541 = $\left\{ A + 4P + 2Q \right\} \times \frac{r}{3}$ = ½ area of midship section.	
	2	
	41·082 = Area of midship section without keel.	

Load-Water Line.

Area of the load-water line or area of the assumed deepest plane of immersion, delineated in Fig. 8, Plate A, on the half-

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breadth Plan, and marked by the curve A B. From the Table of Ordinates, p. 26, we have—

·4	3·0	5·0
·4	6·0	6·3
—	6·1	5·4
·8 = A	3·7	—
—	—	16·7 = Q
	18·8 = P	2
	4	—
	—	33·4 = 2 Q
	75·2 = 4 P	—
	·8 = A	
	33·4 = 2 Q	
	—	
	109·4 = A + 4 P + 2 Q	
	5·5 = r'	
	—	
	5470	
	5470	
	—	
	3)601·70	
	—	
	200·56 = $\left\{ A + 4P + 2Q \right\} \times \frac{r'}{3}$ = ½ area of load-water line.	

200·56 = ½ area of load-water section in superficial feet.
2

401·12 = area of load-water section, which amount of area being divided by 12, will give the number of cubic feet of space that would be contained in a zone of that area of an inch in depth, and that result being again divide by 35, as the number of cubic feet of water equivalent to a ton in weight, will give the number of tons that will immerse the vessel one inch at that line of immersion.

Example.

12)401·12 = area of Load-water Section in superficial feet.

5)33·42 = cubic feet in zone of one inch in depth.

7)6.684

·955 = tons to the inch of immersion at the load-water line.

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Centre of Gravity of the Displacement.

Estimated from Section 1, considered as the Initial Plane.

Distinguishing No. of the Areas.	½ Vertical Areas.			Moments.
From p. 39. 1.	1·104	× 0	.. ..	000·000
2.	6·256	× 1	.. ..	6·256
3.	11·745	× 2	.. ..	23·490
4.	16·069	× 3	.. ..	48·207
5.	17·265	× 4	.. ..	69·060
From p. 38. 6.	16·222	× 5	.. ..	81·110
7.	12·512	× 6	.. ..	75·072
8.	6·900	× 7	.. ..	48·300
9.	1·104	× 8	.. ..	8·832

Moments placed in the Rule.

$$\text{Sum.} = \left\{ A + 4P + 2Q \right\} \times \frac{r'}{3}$$

000·000	6·256	23·490
8·832	48·207	69·060
	81·110	75·072
8·832 = A	48·300	
	183·873 = P	167·622 = Q
	4	2
	735·492 = 4 P	335·244 = 2 Q
	8·832 = A	
	335·244 = 2 Q	
	1079·568 = A + 4 P + 2 Q	
	5·5 = r'	
	5397840	
	5397840	
	3)5937·6240	
	1979·208 = $\left\{ A + 4P + 2Q \right\} \frac{r'}{3}$ =	

sum of the moments of half the displacement from section 1, in intervals of space of 5·5 ft.; and the half displacement in cubic feet by vertical sections is 488·650 (p. 40) cubic ft.; whence it is found, by dividing the moment 1979·208 by 488·650, that the distance of the centre of gravity of displacement from the section 1 is as follows:—

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488·65) 1979·208 (4·05 intervals from 1.
195460 interval = 5·5 ft.

246080
244325

1755 therefore 4·05 × 5·5 = 22·27 ft. = distance of the centre of gravity of the calculated immersed body from 1.

Depth of the Centre of Gravity of the Displacement below the Load-water Section.

Section.	Fore Body. Areas.		After Body. Areas.		Sum of the Areas.			Moments.
1′	From p. 35.	96·61	From p. 39.	103·95	200·56	× 0	=	000·000
2′		85·708		86·44	172·148	× 1	=	172·148
3′		66·18		68·38	134·56	× 2	=	269·12
4′		46·29		49·22	95·51	× 3	=	286·53
5′		27·13		28·96	56·09	× 4	=	224·36

000·00
224·36

224·36 = A

172·148
286·530

458·678 = P
4

269·12 = Q
2

538·24 = 2 Q

1834·712 = 4 P
224·360 = A
538·240 = 2 Q

2597·312 = $\left\{ A + 4P + 2Q \right\}$
·92 = r

5194624
23375808

3)2389·52704

796·509 = $\left\{ A + 4P + 2Q \right\} \times \frac{r}{3}$ =

sum of the moments of the half displacement calculated from the load-water line: the half displacement by horizontal sections is 489·588 (p. 40) cubic feet; the sum of the moments of the half displacement 796·509 ft., being divided by that quantity, will give the distance in intervals of ·92 ft., the centre of gravity of displacement is below the load-water line.

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Half solid of displacement. Moments.

489·558) 796·509 (1·62 intervals of ·92 ft.; therefore

489558	1·62
	× ·92
3069510	
2937348	324
	1458
1321620	
979116	1·4904 ft. = the distance the centre of gravity of the calculated immersed body is below the load-water section.
342504	

Distance of the Centre of Gravity of the Area of the Load-water Section from Section 1.

No. of Section.	Ordinates of Section 1 from the Table, p. 26.	Distances of them in intervals of 5·5 ft. from Section 1.	Moments; being the Product of the Areas by the respective Distances.
1	·4	0	000·00
2	3·0	1	3·0
3	5·0	2	10·0
4	6·0	3	18·0
5	6·3	4	25·2
6	6·1	5	30·5
7	5·4	6	32·4
8	3·7	7	25·9
9	·4	8	3·2

The moments, for summation, put into the rule.

00·0	3·0	10·0
3·2	18·0	25·2
	30·5	32·4
3·2 = A	25·9	
	77·4 = P	67·6 = Q
	4	2
	309·6 = 4 P	135·2 = 2 Q
	3·2 = A	
	135·2 = 2 Q	
	448·0 = A + 4 P + 2 Q	
	5·5 = r'	
	2240	
	2240	
	3)2464·0	
	821·3 = $\{A + 4P + 2Q\} \times \frac{r'}{3}$ =	

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sum of the moments of the half area of the load-water section reckoned from 1; the half area of the load-water section is 200·56 feet (p. 42); the distance, therefore, of the centre of gravity of the load-water section from 1 will be found in intervals of space of 5·5 feet, by dividing the sum of these moments by the half area, thus:—

Half Area.	Moments.	No.
200·56)	821·3333	(4·09 intervals, each
	80224	5·5 ft. in length.
	190933	
	180504	
	10429	

and 4·09 × 5·5 = 22·5 ft. gives the distance of the centre of gravity of the load-water section from section 1 of the drawing.

PART XI.

By the usual Method.—Relative Capacity of the Bodies immersed under the Fore and After Lengths of the Load-water Line.—Per Centage of the Bodies.—Height of the Metacentre as the Comparative Measure of the Stability or Stiffness under Canvas of Vessels of the same dimensions.—Summary of the Results of the Calculations.

RELATIVE capacities of the bodies immersed under the fore and after lengths of equal division of the load-water line—

By former calculations.	
After body immersed contains .	497·79 cubic ft. of space.
Fore body ,, ,, . .	481·70 cubic ft. of space.
Difference	16·09 =

the excess in cubic feet of space of the body displaced under the after half-length of the load-water line over that under the fore-half of the same line—

Sum of the bodies (by former calculation) or whole displacement in cubic feet of space (p. 40). . } 979·49

equal to 9·7949 hundreds of cubic feet of space, whence 16·09,

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or the difference between the two bodies in cubic feet, being divided by 9·7949, or the displacement expressed in terms of the hundreds of cubic feet of space, will give the excess for every hundred cubic feet of the whole displacement.

Displacement in Hundreds of Cubic Feet of Space.	Excess in Cubic Feet of Space.	
9·7949)	16·09000	(1·6 = Ratio of the excess of the after body of displacement over the fore body of the same, denoted by a per centage of the whole displacement.
	97949	
	629510	
	587694	
	·41816	

METACENTRE.

A Measure of the comparative Stability of a Ship, or the Height of the Metacentre above the Centre of Gravity of displacement estimated, from the expression $\frac{2}{3} \int \frac{y^3 dx}{D}$, in which

y = The ordinates of the half-breadth load-water section.

dx = The fluxional increment of the length of the load-water section.

D = Displacement of the immersed portion of the body in cubic feet of space.

Ordinates from the Table.		Cubes of the Ordinates.
Page 26.	·4	00·064
	3·0	27·000
	5·0	125·000
	6·0	216·000
	6·3	250·047
	6·1	226·981
	5·4	157·464
	3·7	50·653
	·4	0·064

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Cubes placed in Sterling's Rule for Summation of

$$\text{Area} = (A + 4P + 2Q) \times \frac{r}{3}$$

00·064	27·000		125·000
00·064	216·000		250·047
	226·981		157·464
·128 = A	50·653		
	520·634	= P	532·511 = Q
	4		2
	2082·536	= 4 P	1065·022 = 2 Q
	1065·022	= 2 Q	
	000·128	= A	
	3147·686	=	$\left\{A + 4P + 2Q\right\}$
	5·5	= r'	
	15738430		
	15738430		
	3)17312·2730		
$\int y^3\,dx$	= 5770·7576	=	$\left\{A + 4P + 2Q\right\} \times \frac{r'}{3}$ =

summation of the cubes of the ordinates of the load-water section; and the height of the Metacentre above the centre of gravity of Displacement is expressed by $\frac{2}{3}\int \frac{y^3\,dx}{D}$, in which expression $y^3\,dx = 5770{\cdot}75$ and $D = 979{\cdot}1$ (p. 40) whence $\frac{2}{3} \times \frac{5770{\cdot}75}{979{\cdot}1} = 3{\cdot}98$ feet is the height of the Metacentre above the centre of gravity of the Displacement.

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Results of the Calculations.

1st Method.

Displacement in Cubic Feet of Space . .	=979·149.
Displacement in Tons of 35 Cubic Feet of Water to a Ton	= 27·974.
Area of Midship Section	= 41·08 superficial feet.
Area of Load-water Line or Plane at the proposed deepest Immersion . . .	=401·12 superficial feet.
Tons to one inch of Immersion at that Floatation	=·955 tons.
Longitudinal Distance of the Centre of Gravity of Displacement from Section 1, Fig. 8.	=22·22 feet.
Depth of the Centre of Gravity of Displacement below the Load-water Section	=1·4904 feet.
Distance of the Centre of Gravity of the Load-water Section from Vertical Section 1	=22·5 feet.
Relative capacity of the After Body in excess of the Fore Body in Cubic Feet of Space	=16·09.
Per Centage on the whole Displacement .	=1·6.
Height of the Metacentre above the Centre of Gravity of Displacement, estimated from the expression $\frac{3}{2} \int \frac{y^3 dx}{D}$.	=3·98 feet.

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PART XII.

Second Method.—The Calculations under the Form of a Double Columned Table of Ordinates.—Displacement.—Area of Midship Section.—Area of Load-water Line.—Position of the Centre of Gravity of Displacement.—Position of the Centre of Gravity of the Load-water Section.—Relative Capacity of the Two Bodies under the Fore and After Half-length of the Load-water Line.—Height of the Metacentre.—Contrasted Elements of the Vessel obtained under the Two Methods.

THE young Naval Architect has thus been led through the essential calculations on the immersed portion of a ship considered as a floating body. The term essential has here been used under a knowledge, that the table of results might have been swollen to a small volume by a lengthened comparison of the elements of the naval construction, such as the ratio of the area of the midship section to the area of the load-water section, and that of the area of the midship section to the circumscribing parallelogram; data that will always suggest themselves to the mind of an inquiring youth, and furnish him with salutary exercise for his judgment, while the introduction of such comparisons into these rudiments might deter the novice from entering on a task that would thence seem to be involved in such voluminous results. For the second method of calculation, the table of ordinates is in two portions, *viz.*, the fore and after bodies under the division of the load-water section into two equal parts, the length of such section being restricted to the distance from the fore-edge of the rabbet of the stem to the after-edge of the rabbet of the post. The enlarged tables are shown at pages 51 and 52, and the directions for the working of these tables have been given at page 11, observing only that the ordinates have not been herein inserted in red in these tables, as it was there suggested, to insure perspicuity and accuracy.

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FORE BODY.—TABLE I.—FIG. 6.

| | | |

AFTER BODY.—TABLE II.

| | | |

Results from the Tables.

By modified rule. Area $= \left\{\frac{A}{2} + 2P + Q\right\}\frac{2r}{3}$

And solid = areas for ordinates summed by rule $= \left\{\frac{A'}{2} + 2P' + Q'\right\} + \frac{2r'}{3}$

Functions of the areas marked B $= \left\{\frac{A}{2} + 2P + Q\right\}$

Function of the solid equal to B, placed in Sterling's Rules = $A' + 2P' + Q' = E$

Whence displacement $= E \times \frac{2r}{3} \times \frac{2r'}{3}$, in the example $r = 92$ $r' = 5{\cdot}5$.

Therefore $\frac{1}{2}$ displacement $= E \times \frac{2r}{3} \times \frac{2r'}{3} = E \times \frac{1{\cdot}84}{3} \times \frac{11}{3} =$

$E \times \frac{20{\cdot}24}{9}$

Value of E from the Tables by Vertical Sections.

Table 1. . 106·50 = submultiple of the fore body by vertical sections.
Table 2. . 110·77 = ,, after body ,, ,,

217·27 = sum of the submultiples = E.

$\frac{1}{2}$ displacement $= E \times \frac{20{\cdot}24}{9} = \frac{217{\cdot}27 \times 20{\cdot}24}{9} = 24{\cdot}14 \times 20{\cdot}24 =$

488·5936 = $\frac{1}{2}$ solid of displacement by the summation of the vertical areas given in cubic feet of space.
2

5)977·1872

7)195·4374

27·92 = Displacement by vertical sections in tons of 35 cubic feet of space.

Value of E from the Tables by Horizontal Sections.

Table 1. . 106·50 = submultiple of the Fore Body by horizontal sections.
Table 2. . 110·75 = submultiple of the After Body by horizontal sections.

From whence the same results will be obtained.

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Area of Midship Section.

From Table 1. . 28·15 = Submultiple of the area of Section 5.
1·84 = 2 *r*

11260
22520
2815

3)51·7960

17·265 = ¼ area of the upper space of the midship section.
3·275 = ¼ area of the lower „ „ below *d d*, Fig. 8.

20·540 = ¼ area of midship section.
2

41·08 = area of midship section.

Area of the Load-water Line.

From Table 1. . 26·35 = submultiple of the area of the fore body.
From Table 2. . 28·35 = „ „ after body.

54·70 = submultiple for the ¼ area of the load-water line.
11 = 2 *r'*

3)601·7

200·56 = ½ area = $\frac{\text{A}}{2} + 2\,\text{P} + \text{Q} \times \frac{2\,r'}{3}$.
2

12)401·12 = area of load-water line.

5)33·42

7)6·684

·955 = tons per inch of immersion at the load-water line.

Position of the Centre of Gravity of Displacement.

By Table 2. . . . 878·86 = Moments from Section 1.
and E. . . . . 217·27 = Corresponding Function of the Displacement.

217·27)878·86(·404 Intervals of 5·5 feet, giving 4·04 × 5·5 = 22·22 feet as the distance of the Centre of Gravity of the Displacement from Section 1.
869·08

97800
86908

10892

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Depth of the Centre of Gravity of the Displacement below the Load-water Section.

By Table 2. . . . 353·72 = Moments from Load-water Line.
and E. . . . . 217·25 = Corresponding Function of the Displacement.

217·25)353·72(1·62 Intervals of ·92 feet, giving 1·62 × ·92 = 1·4904 as the distance that the Centre of Gravity of Displacement is below the Load-water Line.
217·25
136·470
130·350
61200
43450
17750

Position of the Centre of Gravity of the Load-water Line of Deepest Immersion.

From Table 1. . . 26·35 ft.
,, 2. . . 28·35

From Table 2. . 224·000 = Moments from 1st Section.

Function for Area . 54·7) 224·0 (4·09 Intervals of 5·5 feet, giving 4·09 × 5·5 = 22·495 feet as the distance that the Centre of Gravity of the Load-water Section is from Vertical Section 1.
218·8
5200
4923
·277

Relative Capacities of the Calculated Immersed Bodies contained under the Fore and After Lengths of equal Division of the Load-water Line.

	feet.
From Table 1. . Function for the Fore Solid . .	106·50
From Table 2. . Function for the After Solid . .	110·75
	4·25
Sum of the Functions	217·25

The difference, 4·25 feet, expresses the excess in cubic feet of space of the body, displaced under the after half-length of the load-water line, over that under the fore half-length of the

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same line, and the sum of the functions, 217·25, is equal to 2·1725 hundreds of cubic feet of space; whence, 4·25 feet, or the difference between the functions for the two bodies, being divided by the function 2·1725, or the function for the displacement of the calculated body expressed in terms of hundreds of cubic feet of space, will give the excess for every hundred cubic feet of that displacement.

Function of Displacement in Hundreds of Cubic Ft. of Space.	Excess in Cubic Feet of Space.	
2·1725)	4·25000 (	1·9 ratio of the excess of the after body of calculation over the fore body of the same, denoted by a per-centage of the displacement calculated by the Table of Ordinates.
	2·1725	
	207750	
	195525	
	·12225	

Height of the Metacentre above the Centre of Gravity of Displacement.

From Table 2.—The summation of the functions of the cubes of the ordinates for the value of the $f y^3 dx$ . . . . . = 1573·843

The corresponding function for the solid . . = 217·25

from whence the height of the metacentre above the centre of gravity of displacement, expressed by $\frac{2}{3} f \frac{y^3 dx}{D}$ is as follow:

$$f y^3 dx = 1573{\cdot}843 \times \frac{2r'}{3} \text{ where } r' = 5{\cdot}5 \text{ feet} =$$

$$\frac{1573{\cdot}843 \times 11}{3} = \frac{17312{\cdot}273}{3} = 5770{\cdot}75 \text{ feet.}$$

(Page 52) $217{\cdot}27 \times \frac{2r}{3} \times \frac{2r'}{3} = \frac{1}{2}$ displacement $= 488{\cdot}5936$ feet,

whence displacement or D $= 977{\cdot}1872$;

and thence

$$\frac{2}{3} f \frac{y^3 dx}{D} = \frac{2}{3} \times \frac{5770{\cdot}75}{977{\cdot}1872} = \frac{11541{\cdot}53}{2931{\cdot}5616} = 3{\cdot}98 \text{ feet.}$$

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Results obtained under the Two Methods of Calculation contrasted.

	Old Method.	2nd Method.
Displacement in cubic feet of space	979·139	977·187
Displacement in tons of 35 cubic feet of Water to a ton	27·985	27·92
	Superficial ft.	Superficial ft.
Area of Midship Section	41·08	41·08
Area of Load-water Line or Plane at the proposed deepest immersion	401·12	401·12
Tons to one inch of Immersion at Line of Floatation	·9526 tons.	·955 tons.
Longitudinal Distance of the Centre of Gravity of the Displacement from Section 1, Fig. 8.	22·22 ft.	22·22 ft.
Depth of the Centre of Gravity of Displacement below the Load-water Section	1·4812 ft.	1·4904 ft.
Relative Capacities of the Bodies	1·6 per cent.	1·9 per cent.
Height of the Metacentre above the Centre of Gravity of Displacement	3·98 ft.	3·98 ft.

PART XIII.

Method of forming a Curve of Sectional Areas from a Drawing of Ship.—Calculations for the Displacement from it.—Application of the Method to the Yacht of 36 Tons Admeasurement.—Relative Capacity of the Fore and After Bodies of the Yacht pointed out by the Curve.—Area of Midship Section of the same.—Curve of Sectional Areas used to obtain the Centre of Gravity of Displacement.—Application of it to the Yacht of 36 Tons Admeasurement.

THIRD METHOD OF CALCULATION.

Calculations on the Draught of the Yacht of 36 Tons using the Curve of Sectional Areas.

The load-water line, A B, in the sheer plan, Fig. 9, is divided into two equal parts at the point C, and those equal parts are again subdivided at the points D and E; at the

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points C, D, and E, thus obtained, the transverse vertical sections of the vessel are delineated as shown by Fig. 9.

The length of the load-water line from the fore edge of the rabbet of the stem B, Fig. 9, to the after edge of the rabbet of the post A, is next drawn below and parallel to the base line S T, Fig. 9, of the sheer plan, this line, F G, becomes the base line of the curve of the sectional areas. The common sections of the transverse vertical sections of C, D, and E, (which will be straight lines,) with this horizontal and longitudinal plan, are drawn from their respective points of division, H, I, and K, in half-breadth plan, Fig. 9. The areas of these transverse vertical sections at D, C, and E, are then calculated by Sterling's Rules of

$$\text{Area} = \left\{ A + 4P + 2Q \right\} \times \frac{r}{3} = \left\{ \frac{A}{2} + 2P + Q \right\} \times \frac{2r}{3};$$

$$\text{or, Area} = \left\{ A + 2P + 3Q \right\} \times \frac{3}{8} r = \left\{ \frac{A}{2} + P + 1{\cdot}5\,Q \right\} \times \frac{3}{4} r.$$

Half Area of Transverse Vertical Section, at C, by Rule 1,

$$\text{or, } \tfrac{1}{2}\text{ Area} = \left\{ \frac{A}{2} + 2P + Q \right\} \times \frac{2r}{3}$$

1st .. 6·3 2nd .. 6·0 3rd .. 4·8 = Q
Last .. ·2 4th .. 2·3

2)6·5

3·25 = $\frac{A}{2}$

8·3 = P
2

16·60 = 2 P
3·25 = $\frac{A}{2}$
4·80 = Q

24·65 = $\left\{ \frac{A}{2} + 2P + Q \right\}$ 1
·83 = $\frac{2r}{3}$

7395
19720

20·4595 = $\left\{ \frac{A}{2} + 2P + Q \right\} \times \frac{2r}{3}$ =

½ Area of Section C in feet.

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C M, or depth = 5·0 feet, whence $\frac{C\,M}{4}$ or, $\frac{5{\cdot}0}{4} = 1{\cdot}25 = r =$ distance between the ordinates, and $\frac{2\,r}{3} = \frac{2 \times 1{\cdot}25}{3} = \frac{2{\cdot}5}{3} =$ ·83 feet.

Half Area of Section C, by Rule 2.

$$\text{or, } \tfrac{1}{2} \text{ area} = \left\{ \frac{A}{2} + P + 1{\cdot}5\,Q \right\} \times \frac{3}{4} r.$$

1st. ..	6·3	P = 00	5·6	2nd.
Last ..	·2		3·05	3rd.
	2)6·5		8·65 = Q	
	3·25 = $\frac{A}{2}$		4·32 = $\frac{1}{2}$ Q	
			12·97 = 1·5 Q	

$$\left.\begin{matrix} 3{\cdot}25 \\ 12{\cdot}97 \end{matrix}\right\} = \frac{A}{2} + P + 1{\cdot}5\,Q$$

16·22
5 = 3 r = C M = 5·0 ft.
4)81·10
20·275 = ½ area = $\left\{ \frac{A}{2} + P + 1{\cdot}5\,Q \right\} \times \frac{3}{4} r.$

Half Area of the Transverse Vertical Section at E.

1st. ..	5·0	2nd. ..	4·2	3rd. .. 2·9 = Q
Last. ..	·2	4th. ..	1·7	
	2)5·2		5·9 = P	
	2·6 = $\frac{A}{2}$		2	
			11·8 = 2 P	
			2·6 = $\frac{A}{2}$	
			2·9 = Q	
			17·3 = $\frac{A}{2}$ + 2 P + Q.	

E O, or depth = 4·2 feet, whence $\frac{E\,O}{4} = \frac{4{\cdot}2}{4} = 1{\cdot}05 = r =$ distance between the ordinates, and $\frac{2\,r}{3} = \frac{1{\cdot}05 \times 2}{3} = \frac{2{\cdot}1}{3} =$ ·7 feet; therefore,

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Area $= \left\{\frac{A}{2} + 2P + Q\right\} \times \frac{2r}{3} = 17{\cdot}3 \times {\cdot}7 = 12{\cdot}11 =$ half area of transverse vertical section at E.

Half Area of the Transverse Vertical Section at D.

1st. .. 5·40	2nd. .. 3·5	3rd . . 1·46 = Q	
Last. .. 0·2	4th. .. 0·7		
2)5·6	4·2	= P	
2·8 = $\frac{A}{2}$	2		
	8·4	= 2 P.	
	2·8	= $\frac{A}{2}$	
	1·46	= Q	
	12·66	= $\frac{A}{2}$ + 2 P + Q	

D N or depth = 5·8 feet whence $\frac{DN}{4} = \frac{5{\cdot}8}{4} = 1{\cdot}45$ feet = r = distance between the ordinates, and $\frac{2r}{3} = \frac{2 \times 1{\cdot}45}{3} = \frac{2{\cdot}9}{3} = {\cdot}97$ feet; therefore,

Area $= \left\{\frac{A}{2}2 + P + Q\right\} \times \frac{2r}{3} = 12{\cdot}66 \times {\cdot}97 =$ 12·28 feet = half area of transverse vertical section at D.

Half Areas of the Transverse Vertical Sections.

	Feet.		Feet.
At E	= 12·11	Divided by 5 as the depth assumed for the zone, give the ordinates for the curve of sectional areas, as	2·42
C	= 20·20		4·04
D	= 12·28		2·45

of which 2·42 is set off from H as H R, 4·04 ft. from I as I Q, and 2·45 ft. from K as K P; the curve I R Q P G passing through the extremities P, Q, and R of the ordinates P K, Q I and R H is the curve bounding the area of a zone, which to the depth of 5 ft. for a solid, will give in cubic feet of space the half displacement of the immersed body, or the displacement of the yacht to the line A B of proposed deepest immersion.

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To measure this representative area, and from thence the solid, join the points Q, G, and I by the straight lines Q G, Q F, dividing the curvilinear area F R Q P G F into the two triangles Q G I, Q F I, and the two areas G P Q G, F R Q F. The triangles by construction are equal, and the area of each one of them is equivalent to $\frac{G I \times Q I}{2}$, or the whole area

$$G Q F I G = \frac{G I \times Q I}{2} \times 2 = G I \times Q I \text{ or } F I \times I Q,$$

F I being equal to F G, each being the half-length of the same element, the load-water line or line of deepest immersion. The areas Q P G Q, Q R F Q, are bounded by the curve lines Q P G, Q R F, which are assumed as portions of common parabolas, and under such an assumption their respective areas are equal to $\frac{2}{3}$ of the circumscribing parallelograms, or the area Q P G Q $= \frac{2}{3}$ of G Q $\times$ x, and the area F R Q F $= \frac{2}{3}$ of F Q $\times$ x' where x and x' are the greatest perpendiculars that can be drawn from the bases Q G and Q F to meet the curves Q P G, Q R F.

Fig. 9. Plate B.

Example.

Yacht of Thirty-six Tons.

Displacement.

Example.

A B by a scale of parts = 44 ft., whence F I or F G equal $\frac{AB}{2} = \frac{44}{2}$ ft. = 22 ft.; ordinate Q I of the medial section = 4·04 ft.; and Q G = F Q being the respective hypothenuses of the equal triangles, Q G I, Q F I are each equal to

$$\sqrt{F G + Q I^2} = \sqrt{22^2 + 4{\cdot}04^2} = \sqrt{484 + 16{\cdot}32}$$

$$= \sqrt{500{\cdot}32} = 22{\cdot}37 \text{ ft. and } x \text{ by measurement with a scale}$$

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of parts = ·6 ft. and x' also ·6 ft. from which datæ the half displacement in cubic feet of space will be obtained as follows:

	Cubic feet.
Area F Q G I F = G I × I Q.	
Solid under the area F Q G I F = G I × I Q × 5 = 22 × 4·1 × 5 =	451·00
Area Q P G Q = $\frac{2}{3}$ of G Q × x	
Solid under the area Q P G Q = $\frac{2}{3}$ of G Q × x × 5 = $\frac{2}{3}$ × 22·37 × ·6 × 5 =	44·74
Area F R Q F = $\frac{2}{3}$ of F Q × x'	
Solid under the area F R Q F = $\frac{2}{3}$ of F Q × x' × 5 = $\frac{2}{3}$ × 22·37 × ·6 × 5 =	44·74
	540·48

or area of the triangle Q G I + area of the triangle Q F I, + area of the space Q P G Q + area of the space F R Q F = to the representative area F R Q P G, which being multiplied by the assumed depth of 5 ft. for the zone of half displacement gives 540·48 cubic feet of space, which divided by 35 as the number of such cubic feet that are equivalent to ton of medium water gives

5)540·48

7)108·09

15·44 tons for half displacement,

and that the whole weight of the body is equal to 15·44 × 2 = 30·88 tons = displacement to the line of proposed deepest immersion A B.

Relative Capacities of the Bodies immersed under the Fore and After Half-lengths of the Load-water Line, as given by the Delineated Curve of Sectional Areas.

The triangles Q G I and Q F I being equal, the relative capacities of the fore and after bodies will be determined by the proportion that the area Q P G I bears to the area Q R F I, and as these areas involve two equal terms, or that

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the base F Q = the base Q G, it follows, that the relation of these areas to each other will be expressed by the proportion that the perpendiculars x and x' bear to each other. In the example given, the fore and after bodies or the displacements under the fore and after half-lengths of the load-water A B are equal; as the perpendiculars x and x' taken from the diagram, Fig. 9, on a scale of equal parts, are each ·6 of a foot.

The area of the midship section is denoted relatively by the medial ordinate of the curve of sections Q I, and the full amount of it is obtained by multiplying the function Q I by the depth of the zone M. In the example:

M = 5; Q I = 4·04: then half area of medial section = 4·04 × 5

5

Area of midship section . . 20.20

Centre of Gravity of Displacement by the Curve of Sectional Areas.

An approximation to the common centre of gravity of the representative area of the zone, for the solid of displacement under the division of it into four portions, as shown in Fig. 9, may be obtained as follows:

The centre of gravity of the two triangles, from their being equal, will be in the medial section Q I, and the common centre of gravity of the four portions of division will thence depend on the relative capacities of the parabolic portions of the representative area, and the positions of their respective centres of gravity.

The position of the centre of gravity of each of the parabolic portions of the representative area may be approximated to, by dividing the hypothenuse into two equal parts and drawing a line from the point of subdivision perpendicular to that line and meeting the curve of sectional areas; the centre

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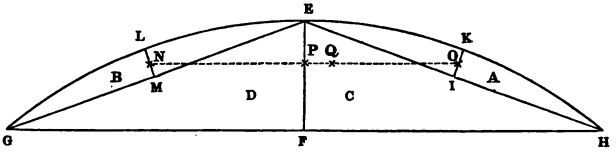
of gravity of the respective portions may be then taken along this line at $\frac{2}{3}$ of it from the curve, and its corresponding solid of displacement may be considered in position at that centre, under which considerations the common centre of gravity of these parabolic portions may be found by equating the moments of them from the centre of gravity of either of them, thus in Fig. 10, under the division of the curve of sectional areas before given, if

FIG. 10.



A = fore parabolic portion of the representative area for the half solid of displacement.

B = after ditto; C, the fore-triangular portion of the same area, and D = the after-triangular portion of it, and the hypothenuses E H and G E be bisected in the points I and M, and perpendiculars I K and M L be drawn from these points to meet the curve of sections G E H in the points K and L, then $\frac{2}{3}$ of F K equivalent to K O, and $\frac{2}{3}$ of L M equivalent to L N, will be the approximate distances of the centres of gravity of the parabolic portions of the representative areas from the curve G E H, taken along the lines K I and L M. Join O N and putting x for the distance of the common centre of gravity of the two parabolic portions, A and B from N, and considering the volumes A and B to be in position at their respective centres of gravity, the equation of moments will be as follows:

$$x \times \{A + B\} = A \times ON$$

from which equation, if the value of O N, the distance, that the centres of gravity of the parabolic portions A and B are

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apart, be measured by a scale of parts, and A and B be taken in value, the cubic feet of space due to those portions, and these known quantities be substituted in the equation of moments, for their several corresponding terms, the value of x may be determined. Let $x = NQ$, whence PQ, which is equal to NQ − NP, is known, for which substitute a, then $\{A + B\} \times a =$ moment of $\overline{A + B}$ from medial section, and the common centre of gravity of the portions D and C is in the medial section, from which the common centre of gravity of A, B, D, and C, or of the half displacement from the medial section EF, may be found by the equation of moments.

$$\overline{A + B} \times a + \overline{D + C} \times O = \{A + B + D + C\} \times x$$

$$\text{or } \overline{A + B} \times a = \{A + B + D + C\} \times x$$

$$\text{Whence } x = \frac{\{A + B\} \times a}{A + B + D + C} = \frac{\{A + B\} \times a}{\frac{1}{2} \text{ Displacement,}}$$

and the value of x thus obtained being set off on the straight line G H from the point F, will give the position of the centre of gravity of displacement.

In the example given for the construction drawing of a yacht of 36 tons.

From Fig. 10.

A = 44·74 feet.
B = 44·74 feet. } whence A + B = 89·48.
C = 225·50 feet.
D = 225·50 feet.
And A + B + C + D = 540·48 feet, equal to the half displacement.

$LM = \cdot 6$, whence $LN = \frac{2}{3}$ of $LM = \frac{2}{3}$ of $\cdot 6 = \cdot 4$, and

$KI = \cdot 6$, whence $KO = \frac{2}{3}$ of $KI = \frac{2}{3}$ of $\cdot 6 = \cdot 4$,

and the points N and O are the positions of the centres of gravity of the curvilinear spaces GLEG, EKHE, whence NO may be measured by a scale of equal parts, and from

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thence P Q be determined. For by the equation of moments, $x \times \overline{A + B} = A \times N O$, where N O by measurement = 16 feet, and x = N Q, the point Q being assumed.

$N Q \times \overline{A + B} = A \times N O$ from which by substitution

$$N Q \times 89{\cdot}48 = 44{\cdot}74 \times 16, \text{ or } N Q = \frac{715{\cdot}84}{89{\cdot}48} = 8 \text{ feet,}$$

which 8 feet being set off from N along the line N O gives the position of the point Q, from whence, by measurement, P Q may be found equal to ·75 feet = a of the formula, in which x, or distance of the centre of gravity of displacement from the medial section $= \frac{\overline{A + B} \times a}{A + B + C + D} = \frac{\overline{A + B} \times a}{\frac{1}{2} \text{ displacement,}}$

or, by substitution, $x = \frac{89{\cdot}48 \times {\cdot}75}{540{\cdot}48} = {\cdot}12$ feet, the distance the centre of gravity of displacement is before the medial section E F.

PART XIV.

General Terms of the Curve of Sectional Areas when applied to Naval Construction.—Practical Operations under that System to the Yacht of 36 Tons Admeasurement. — The Method applied to the Construction of a Frigate whose Displacement is 2,300 Tons.

The Curve of Sectional Areas applied to Naval Construction.

A consideration of the armament and its weight, of the number of men necessary to work and fight the ship, with the weight of the provisions and stores for the particular service on which it is intended to employ her, and the weight of her hull or fabric, when completed, will fix the amount of displacement to be given to a naval construction.

The arrangement of that displacement, under the dimen-

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sion of the length, breadth, and draught of water, that have been determined on by the constructor, constitutes the theory of Naval Architecture; and the proposed method will be found to facilitate, in no inconsiderable degree, the construction of men-of-war and steam-vessels, and will form a register, by which, from observation and practical results, the best form to be given to them may eventually be determined.

The displacement of the ship, under the considerations before stated, having been decided on,—and the relative capacities, under the fore and after half-lengths of the load-water line, having been fixed, with reference to the stowage and internal arrangements of the ship,—the area of the vertical section, ("at the middle of the load-water line,") is next to be determined; for which the following equation will hold good by the variation of the decimal part of it to the views of the constructor, or the peculiar service required of the ship; as, under a given displacement, this element, the "area of the immersed midship section," will regulate the degree of fulness of the bow and quarters of the ship:—

Length on the load-water line, from the fore-part of the rabbet of the stem, to the after-part of the rabbet of the post multiplied by area of midship section multiplied by decimal fraction = displacement. As an example: the decimal fraction of ·7 has been found to give the area of midship section, well adapted for frigates. Or, the equation to stand thus:—

$$\text{Area of midship section} = \frac{\text{Displacement in cubic feet}}{\text{Length of load-water line} \times \cdot 7}.$$

The area of the midship section having been determined, for the convenience of placing a curve of vertical sectional areas on paper, take a submultiple of that area, by dividing the half-area of the midship section by a quantity that will give a quotient less than the half-breadth of the ship, and call this the "middle ordinate of the curve of sectional areas;" or, of a curve, which will, under the length of the load-water line, bound an area, that, to the depth assumed, will form a solid equivalent to

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the half-solid of displacement. Next set-off the length of the load-water line, under the points before given; divide that length into two equal parts; and set up, at the middle thus obtained, the "middle ordinate of the curve of sections;" complete the triangles, by joining the extremes of the load-water line and the extremes of the "middle ordinate of the curve of sections;" and find the areas of these triangles, which are similar and equal by construction. The respective differences between the intended half-displacements, in cubic feet, under the fore and after half-lengths of the load-water line, and the areas of these triangles will give the required areas to be developed under the curves on the hypothenuse of each triangle, which shall, with the areas of the triangles, make up a submultiple of the half-displacement; and the ordinates of these curves, measured perpendicularly from the base line, or line representing the length of the load-water line, will be submultiples of the area of each transverse section of the immersed body.

The proposed Method of Construction, stated in General Terms.

Let the displacement = D; and take the difference of the respective capacities of the bodies, or the excess of the fore body over the after body, under the fore and after half-lengths of the load-water line, as 4 per cent. of the whole displacement. Let A B C, Fig. 11, equal the length on the load-water line; B D = the "middle ordinate of the curve of sections;" join A and D, D and C, thus completing the triangles A B D and D B C, which, by construction, are similar and equal. To determine the lines E F and G H, the abscissa of each curve required, the following equations must be eliminated. The half-displacement, represented as an area of a zone to a common depth assumed, is to be bounded by a curve A H D F C and the base A B C, the length of the load-water line; and the part D B C F, under the fore half-length B C of A B C, is in excess of the part D B A H, under the after half-length A B of

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the load-water line A B C, by 4 per cent. on the half-displacement. Or,

The area D B C F . . . $= \frac{D}{4} + \frac{4D}{400} = \frac{D}{4} + \frac{D}{100} = \frac{26D}{100}$.

The area D B A H . . . $= \frac{D}{4} - \frac{4D}{400} = \frac{D}{4} - \frac{D}{100} = \frac{24D}{100}$.

The area D E C F . . $= \frac{2}{3}$ E F × D C
The area D G A H . . $= \frac{2}{3}$ G H × A D
} if considered to approximate to a common parabola.

By construction, area D E C F − area D G A H $= \frac{4D}{200} = \frac{2D}{100}$ } As the fore body of displacement is to exceed the after body by 4 per cent. on the whole displacement.

Also, by construction, area D E C F + area D G A H $= \frac{D}{2}$ − twice area of the triangle C B D, or A B D.

Or, $\frac{2}{3}$ E F × D C − $\frac{2}{3}$ G H × A D $= \frac{4D}{200} = \frac{2D}{100}$ (1).

$\frac{2}{3}$ E F × D C + $\frac{2}{3}$ G H × A D $= \frac{D}{2}$ (2 area of triangle CBD) (2).

Or, by adding 1 and 2 together, $\frac{4}{3}$ E F × D C $= \frac{2D}{100} + \frac{D}{2}$ − (2 area of the triangle CBD).

In which equation E F is the only unknown quantity, and the value of it can thence be easily determined; and, when found, if substituted in equation, 1 or 2, the value of G H, will be known. The dimensions for the abscissa of the curves being thus fixed, the respective positions of them along the hypothenuse of the triangles C B D or A B D, will remain to be determined by the views of the constructor, as on the position chosen depends the character of the bow and quarter of the ship. D E = $\frac{2}{3}$ of D C, and D G = $\frac{2}{3}$ of D A have been found to give a curve of sections A D C, which is best adapted for a man-of-war, under the present stowage and internal arrangements. The curve of sectional areas is then made to A H D F C, pass through the points A, H, D, F, and C, forming the representative area of the zone for the half-displacement.

The constructor has next to delineate, according to his ideas, the load-water line, and the form of the midship section, en-

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closing the area proposed to be immersed; and having done which, the load-water line will form the boundary of the final ordinates of the respective areas of each transverse section of the immersed body; and the areas given by the curve of sections will develop the form of them; and the bodies (fore and after) will thence be balanced, and the required displacement ensured.

Curve of Sectional Areas and Zone of Displacement applied to the Construction of the Yacht of 36 tons admeasurement.

The whole displacement was taken at 30·88 tons of medium water of 35 cubic feet to the ton.

Giving the whole displacement as 1080·96 cubic feet of space,
and the half ,, as 540·48 ,, ,,
Length on the water-line assumed to be 44 feet.
Breadth . . . . . 12·6 feet.
The area of midship section taking as being equal to

$$\frac{\text{Displacement}}{\text{Length of Load-water Line} \times \cdot 6} = \frac{\text{Cubic Feet. } 1080 \cdot 96}{44 \times \cdot 6} = \text{Superficial Feet. } 40 \cdot 9$$

The capacities of the Fore and After Bodies were made equal;

Or, Fore Body = 540·88 cubic feet of space.
After Body = 540·88 ,, ,,
Whence 270·44 = half fore body in cubic feet of space.
270·44 = half after body ,, ,,
20·45 = half area of midship section.
6·3 = half breadth.

Dividing the half area of the midship section by 5, as the depth of the zone, gives 4·09 feet for the "middle ordinate of the curve of sections," and 5 becomes the multiple for the representative areas or the depth of the zone.

The length of the load-water line divided by 2 $= \frac{44}{2}$ ft. = 22 ft. = F I or FG. (Fig. 9, Plate B.) The representative area Q I G or Q I F $= \frac{\text{I G} \times \text{I Q}}{2}$

$$= \frac{22 \times 4 \cdot 09}{2} = 11 \times 4 \cdot 09 = 44 \cdot 99 \text{ feet.}$$

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	Cubic Ft.
The zone or solid under Q I G = Q I G × 5 = 44·99 × 5 =	224·95
The half fore body equals . . .	270·44
Difference	45·49

being equal to the solid under the parabolic area Q P G Q.

The length of the hypothenuse Q G by calculation $= \sqrt{22^2 + 4{\cdot}09^2}$
$= \sqrt{484 + 16{\cdot}72} = \sqrt{500{\cdot}72} = 22{\cdot}37$ feet.

To find the value of the abscissa x of the parabolic area Q P G Q, subsituting the foregoing values in the equation.

(P. 69.) $\frac{4}{3}$ of Q G × x × depth of zone $= \frac{D}{2} + \frac{2D}{100} - 2 \left\{$ area Q I G × depth of the zone, or $\frac{4}{3}\ x \times 22{\cdot}37 \times 5 = \frac{D}{2} - 2$, area of Q I G × 5 as $\frac{2D}{100}$ is equal to nothing, there being no difference between the bodies;

whence $\frac{4}{3}\ x \times 22{\cdot}37 \times 5 = 540{\cdot}48 - 449{\cdot}90$

$447{\cdot}4 \times x = 3 \times 90{\cdot}58$

$= 271{\cdot}74$

and $x = \frac{271{\cdot}74}{447{\cdot}4} = {\cdot}6.$

The value of x' is the same; the portions of the displacement under the fore and after lengths of the load-water line, or line of deepest immersion, having been assumed equal; the positions of x and x' along the hypothenuses Q G and Q F have in this example been taken at $\frac{1}{3}$ of each respectively, or of Q G and Q F from Q, the curve traced through the points Q, and the extremes of x and x', (p. 61,) will be the boundary of an area representative of the surface of the half solid of displacement, under a zone 5 feet in depth; and the ordinates of that curve, multiplied by 5, will give the areas of the respective vertical and athwartship immersed sections at each position, thus:—

P K measures, by a scale of parts, 2·45 feet; which, multiplied by 5, gives 12·25 feet as the area of the immersed section O of the sheer plan; and the curve descriptive of the form of the body at the station having been delineated,

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following the form of the midship section enclosing that area, and the constructor having done the same for consecutive sections, he will have furnished sufficient data to enable the draughtsman to fair the design, in which he will have ensured the correct amount of displacement assumed by him, and a distribution of it under the fore and after lengths of the load-water line that will be in accordance with his proposed arrangements for stowage and form.

Proposed Method of Construction, applied to a Particular Example.

Frigate of 2,300 tons moulded displacement.

Given { Displacement = D = 2,300 tons = 80,500 cubic feet of 35 to the ton, and half-displacement = 40,250.
Length on the load-water line assumed = 172 feet.
Breadth „ „ = 46 feet.

Then area of midship section $= \frac{\text{Displacement}}{\text{Length of load-water line} \times \cdot 7} = \frac{\text{Cubic ft. } 80{,}500}{172 \times \cdot 7} = 668$ ft.

Taking the relative capacities, as before stated, of 4 per cent. on the whole moulded displacement, will give on the 2,300 tons, 92 tons.

The half-displacement .	= 1,150 tons	
The half-difference of the Capacities . .	= 46 „	
Sum . . .	1,196 =	Capacity of fore body.
Difference .	1,104 =	„ of after body.
Whence . . .	589 =	½ fore body = D F C B.
	552 =	½ after body = D H A B.

Or, 20,930 cubic feet for ½ fore body, each ton being considered equivalent to 35 cubic feet of space.

19,320 cubic feet for ½ after body.

Half-area of midship section = 334 feet.

Half-breadth . . . . . = 23 feet.

Dividing the half area of midship section by 30, gives 11·1 ft. for the "middle ordinate of the curve of section," and 30 becomes the multiple for the representative areas or depth of the zone.

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The length of the load-water line divided by 2 = 86 ft. = A B or B C.

The representative area A B D or C B D $= \frac{BC \times BD}{2} = \frac{86 \times 11{\cdot}1}{2}$ or 477·3 ft.

which multiplied by 30 gives 14,319 ft. for the displacement of the triangular portion of the zone.

And the displacement of half-fore body . .	= 20,930 cubic ft.
Area of triangle D B C	= 14,319 „ „
Difference equal to the representative area bounded by the curve D E C F . . .	= 6,611 cubic ft.

The length of the hypothenuse D C, by calculation = 87·8 ft.

To find E F, substitute these values in the equation:

$$\frac{4}{3} \text{ E F} \times \text{D C} = \frac{\text{D}}{2} + \frac{2\,\text{D}}{100} - 2 \text{ (area of triangle A B D or CBD),}$$

$$\frac{4}{3} \text{ EF} \times 87{\cdot}8 \times 30 = \left(\frac{\text{D}}{2} + \frac{2\,\text{D}}{100}\right) - 2 \text{ (area of triangle A B D),}$$

$$4 \text{ EF} \times 87{\cdot}8 \times 10 = 40{,}250 + 1{,}610 - 28{,}638.$$

$$\text{E F} \times 3{,}512 = 12{,}889$$

Or E F = 3·76 feet.

And to find the value of G H, we have $\frac{2}{3}$ of E F × D C − $\frac{2}{3}$ G H × A D $= \frac{2\,\text{D}}{100}$

$$= \tfrac{2}{3}\ 3{\cdot}76 \times 87{\cdot}8 \times 30 - \tfrac{2}{3} \text{ G H} \times 87{\cdot}8 \times 30 = 1{,}610$$

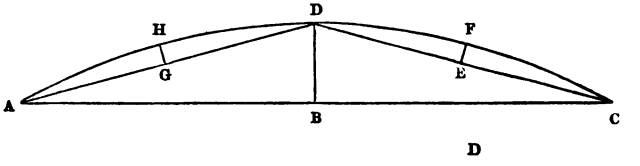
$$2\ 3{\cdot}76 \times 87{\cdot}8 \times 10 - 2 \text{ G H} \times 87{\cdot}8 \times 10 = 1{,}610$$

$$6602{\cdot}56 - 1{,}610 = 1{,}756 \times \text{G H, or G H} = \frac{4992{\cdot}56}{1756{\cdot}} = 2{\cdot}84 \text{ ft.}$$

Or G H = 2·84 ft. nearly. Also, D E $\frac{2}{3}$ of D C = $\frac{2}{3}$ of 87·8 = 58·7 ft. for the position of the abscissa, F E, from D on the line D C.

A consideration of this groundwork of a simple and certain method of construction, will carry conviction of its utility and great capability. The demonstration of it is not strictly true, in the mathematical sense of that word; but it is founded on that rock; and when the method is practised, it will never deceive, and will very materially lighten the labours of the naval constructor.

FIG. 11.



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PART XV.

Preliminary Remarks.—Methods of Calculation for the Areas of the Sails.—Method of finding the Centres of Gravity of Sails, and determining the Position of the Centre of Effort of the Moving Force or the Sails of a Ship.

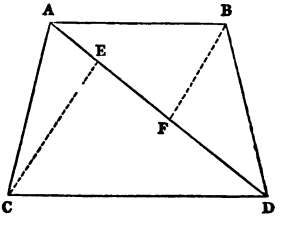
HAVING made the principal calculations on the immersed portion of a ship or her displacement, the quantity of sail and its distribution, or the moving force required with relation to the form of the vessel, is the next subject that demands the attention of the Naval Architect. To pass through the mazes that envelop the theory of resistances with which this part of the science, the area of sails, is connected, will not be attempted in this rudimentary work, as such attempts would be highly speculative, not within the assumed attainments of the novice, and would, moreover, yield results of but little practical utility, and thence would be unworthy of the time which must be bestowed on their development.

A plan of the sails having been delineated by the draughtsman, the areas, centres of gravity, and centre of effort, or the centre of pressure of them are found in the following manner.

AREA OF THE SAILS THAT ARE IN FORM TRAPEZOIDS.

A B C D is a trapezoid, the side A B being parallel to C D, and is of the form of the top-sails, courses, and what is termed the square-sails of a ship. This figure is divided into two triangles by the diagonal A D, and to find the areas of these triangles, the perpendiculars,

FIG. 12.



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C E and B F to A D, are drawn from the apex of the respective triangles A C D and A B D, under which construction the

$$\text{Area of the triangle A C D} = \frac{\text{A D} \times \text{C E}}{2},$$

$$\text{Area of the triangle A B D} = \frac{\text{A D} \times \text{B F}}{2},$$

and the Area of the whole figure A B C D =

$$\frac{\text{A D} + \text{C E}}{2} + \frac{\text{A D} \times \text{B F}}{2} = \text{A D} \times \frac{\text{C E} + \text{B F}}{2}.$$

Area of the Sails that are Triangles.

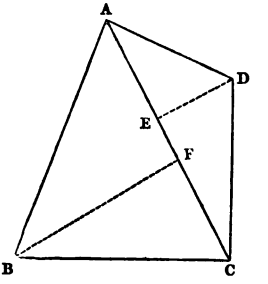
In jibs, fore-topmast stay-sails, and all sails triangular in form, the areas are found by multiplying the base into the perpendicular to that base, drawn from the apex of the triangle, the product being divided by 2, or area =

$$\frac{\text{base} \times \text{perpendicular from the apex to the base}}{2}.$$

Area of the Sails that are Trapeziums or Quadrilaterals that have not their opposite Sides parallel.

A B C D is a trapezium, and is the form of the driver or boom-mainsail of a ship and that of the mainsail of a cutter, and fore and aft sails of schooners. A B C D is divided by the diagonal A C into the two triangles, A B C and A D C; B F and D E are drawn perpendicular to A C from the points B and D of these triangles, from which construction the area A B C = $\frac{\text{A C} \times \text{B F}}{2}$ and area A D C = $\frac{\text{A C} \times \text{D E}}{2}$ and the

Fig. 13.



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$$\text{whole area A B C D} = \frac{\text{A C} \times \text{B F}}{2} + \frac{\text{A C} \times \text{D E}}{2} = \text{A C} \times \left\{\frac{\text{B F} + \text{D E}}{2}\right\}$$

The sum of the areas of the sails, which in form are comprehended by the three examples given, will be obtained by the summation, under the methods laid down, of all the areas delineated in the plan of the sails.

To find the Centres of Gravity of the Sails.

When of a triangular form, as the jib and fore-topmast stay-sail, &c.

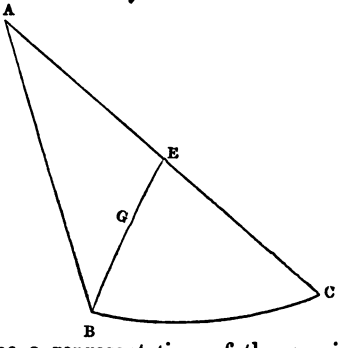

Fig. 14.

Let A B C be a representation of the required sail, then bisect A C in E, join B and E, when $\frac{2}{3}$ of B E = B G = distance of the centre of gravity of the triangle A B C from B, which call G, or centre of gravity of the sail.

When of the form of a trapezoid, as the top-sails, courses, and top-gallant-sails, &c.

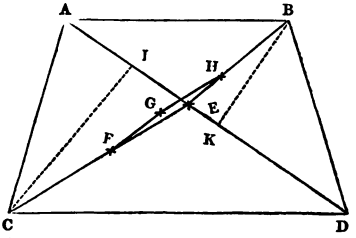

Fig. 15.

Let A B C D represent a top-sail of the form of a trape-

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zoid, A B being parallel to C D; join A and D, dividing the trapezoid into the triangles A C D and A B D; bisect A D in the point E, and join C and E, B and E; then the centre of gravity of the triangle A C D will be at the point F which is $\frac{2}{3}$ of C E set-off from C, and the centre of gravity of the triangle A B D will be at the point H which is $\frac{2}{3}$ of B E from B, and the area of the triangle A C B as before shown is equal to $\frac{A D \times C I}{2}$ and the area of the triangle A B D = $\frac{A D \times B K}{2}$ where C I and B K are perpendiculars from the points B and C of the triangles on the base A D, and the whole area A B C D =

$$\frac{A D \times B K}{2} + \frac{A D \times C I}{2} = A D \times \left\{\frac{B K + C I}{2}\right\}$$ whence

we have the moments from H, as, area of A B C D × G H = area of A C D × F H, or A D × $\left\{\frac{B K + C I}{2}\right\}$ × G H

$$= \frac{A D \times C I}{2} \times F H,$$

or if G H = x, x = F H × $\frac{A D \times C I}{2} \times \frac{2}{A D \times \{B K + C I\}} = \frac{F H \times C I}{B K + C I}$ = distance of the centre of gravity of the area A B C D from the point H, the centre of gravity of the triangle A B D, being given in position. The same formula will apply to the sails that are trapeziums.

Centre of Effort of the Sails.

The areas of the sails and the positions of their centres of gravity having been individually determined by one of the foregoing rules, the centre of effort of them is usually found by assuming, but not necessarily so, an initial plane at the fore extreme of the load-water line, from this plane (which will be represented by a line on the drawing) the distances, by a scale of parts, are taken to the respective centres of gravity of the several sails shown on the drawing, which distances when multiplied into the respective areas of those sails, give the moment of each

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sail from the assumed plane: and the sum of these moments being divided by the sum of the areas of the respective sails, or the total area of sail, will give the distance of the common centre of gravity of the sails from it. This is supposing that the centres of gravity of the respective sails are all situated on the one side of the assumed plane; should the contrary be the case, and that some of them are on the reverse side of the plane, then the difference between the moments of those which fall on either side, divided as before by the whole area of sails, will give the distance the common centre of gravity of them is from the initial plane. This gives the position of the centre of effort of sail with respect to the length of the load-water section. To find its height from that plane, the load-water section, take from the drawing of the sails, by a scale of parts, the height of the centre of gravity of each sail from the load-water line; this distance for each sail, multiplied by the area of the same, will give its moment of height from that plane; and the sum of such moments for all the sails, being divided by the whole area of sails, will give the height of the centre of gravity of them from the load-water line. The position of the centre of effort of the sails will thus be fixed; for the centres of gravity of the same systems of areas having been ascertained for length and height, it follows, that the point in the which they meet is the common centre of gravity of that system, and thence the centre of effort of the sails which it represents.

Application of the Rules for Calculating the Area of the Sails and the Position of the Centre of Effort of the Sails, to a Yacht of 36 Tons.

In Fig. 16, Plate E, or a Delineation of the Sails,

A B C is the Jib.
D E F is the Fore-sail,
G I K H is the Main-sail.
H G H is the Gaff Top-sail.
L M O N is the Mizen.

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These sails having been severally divided for calculation as directed by the Rules.

A′ B′ the representative plane from which the moments for the position of the centre of effort lengthways are reckoned.

Area of Sails.

Feet.

Jib $= \frac{50{\cdot}8 \times 17{\cdot}4}{2} = 25{\cdot}4 \times 17{\cdot}4 = 441{\cdot}96 = \frac{A\,C \times B\,P}{2}$.

Fore-sail $= \frac{36 \times 15{\cdot}4}{2} = 18 \times 15{\cdot}4 = 197{\cdot}20 = \frac{E\,D\,F \times E\,G}{2}$.

Main-sail $= 50{\cdot}4 \times \frac{25 + 12{\cdot}4}{2} = 25{\cdot}2 \times 37{\cdot}4 = 942{\cdot}48 = GK \times \frac{(IS + HT)}{2}$.

Gaff, Top-sail $= \frac{43{\cdot}0 \times 19{\cdot}8}{2} = 21{\cdot}5 \times 19{\cdot}8 = 425{\cdot}70 = \frac{h\,l \times G\,Z}{2}$.

Mizen $= 30{\cdot}4 \times \frac{20 + 9{\cdot}6}{2} = 15{\cdot}2 \times 29{\cdot}6 = 449{\cdot}92 = \frac{LO \times \overline{Mc + Na}}{2}$.

2457·26 Area of Sails in Superficial Feet.

Positions of the Centres of Gravity of the Sails.

Jib $= \frac{2}{3}$ of B P from B $= \frac{2}{3}$ of 17·4 feet $= 11{\cdot}6$ feet from B $= y$.

Fore-sail $= \frac{2}{3}$ of E Q $= \frac{2}{3}$ of 18 $= 12$ feet from E $= r$.

Main-sail, Triangle G I K $= \frac{2}{3}$ of I R $= \frac{2}{3}$ of $28{\cdot}2 = 18{\cdot}8$ feet from I = W.

Main-sail, Triangle G H K $= \frac{2}{3}$ of H R $= \frac{2}{3}$ of $13 = \frac{26}{3} = 8{\cdot}8$ feet from H = V.

Common Centre of Gravity of Main-sail or G I K H $= \frac{W\,V \times IS}{IS + HT} = \frac{13{\cdot}8 \times 25{\cdot}0}{25{\cdot}0 + 12{\cdot}4} = \frac{34{\cdot}5}{37{\cdot}4} = 9{\cdot}2$ ft. from V $= u$.

Gaff Top-sail $= \frac{2}{3}$ of G Z $= \frac{2}{3}$ of 19·8 feet $= 13{\cdot}2$ feet from G $= x$.

Mizen or L M O N: Triangle L M O $= \frac{2}{3}$ of M $b = \frac{2}{3}$ of $21 = 14$ ft. from M.
Triangle L N O $= \frac{2}{3}$ of N $b = \frac{2}{3}$ of $10 = 6{\cdot}6$ ft. from N.

Common centre of gravity of mizen or L M O N $= \frac{n\,o \times Mc}{Mc + Nd} = \frac{10{\cdot}4 \times 20}{20 + 9{\cdot}6} = \frac{208{\cdot}0}{29{\cdot}6} = 7{\cdot}0$ ft. from O $= p$.

$n\,o$, by measurement, $= 10{\cdot}4$ feet.

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Centre of Effort from A′ B′.

Sail.	Areas.	Positions of the Centres of Gravity.	Distances from A′ B′.*	Moments.	
Jib ..	441·96	y	= 2·2 =	972·312	to be subtracted,
Fore-sail..	197·20	r	= 12·0 =	2366·400	add being before A′ B′
Main-sail .	942·48	u	= 32·0 =	30159·360	add
Gaff top-sail .	425·70	x	= 26·0 =	11068·200	add
Mizen ..	449·92	p	= 60·0 =	26995·200	add
Area =	2457·26			70589·160	
				972·312	

2457·26) 69616·848 (28·33 ft. from A′ B′ = Moments of sails from A′B′

491452

2047164
1965808

813568
737178

763900
737178

26722

Centre of Effort from Load-Water Line.

Sail.	Area.	Positions of the Centres of Gravity.	Distances from Load-water Line.*	Moments.
Jib ..	441·96	y	= 18·0 ..	7955·28
Fore-sail ..	197·20	r	= 16·0 ..	3155·20
Main-sail..	942·48	u	= 25·0 ..	23562·00
Gaff top-sail	425·70	x	= 52·8 ..	22476·96
Mizen ..	449·92	p	= 15·0 ..	6748·80
Area =	2457·26			63898·24 (25·9 ft.

491452

1475304
1238630

2366740
2211534

155206

* These distances are measured by a scale of parts, from the plans of the sails being square distances of the centres of gravity from the initial plane A′ B′.

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From which results the position of the centre of effort of the sails may be determined, there being two co-ordinates to fix the place, the one measured from A′ B′ parallel to the load-water line, and equal to 28·3 feet; the other on a perpendicular to the load-water line, and equal to 25·9 feet; and the point where these intersect, marked thus, ⊙, on the plan, denotes the position of the centre of effort.

PART XVI.

Scale of Capacity for the Yacht of Thirty-six Tons Admeasurement.

On the Sheer Plan, Fig. 8, Plate A., according to the directions given at p. 22, A B being the load-water line or the line of deepest immersion, *b b* and *d d* are drawn parallel to A B, and these lines denote the immersions to which the displacements are calculated to form the proposed scale of capacity.

The curve of sectional areas for the immersion A B has been described, Fig. 9, Plate B, and from thence the zone for the displacement has been calculated (p. 62), and found to be equal to 30·88 tons.

Displacement to the Immersion (*b b*), by Curve of Sectional Areas, and Zone formed by it.

To obtain the equal spaces of division required for the use of Sterling's Rules, take a scale of parts, and keeping one of the divisions of it well to the base line of the area to be measured, move the scale to meet the extreme ordinate of the area at any equal number of divisions of the scale, then the intermediate equal divisions will give points through which, if lines be drawn parallel to the base line, the area will be divided into an even number of spaces, and the ordinates will be an odd number for the use of the first rule given by Sterling.

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Half Area of the Vertical Section 2, Fig. 8, Plate A, when immersed to the depth of $b\,b$, or 2·1 ft.

1st . . 2·25	2nd . . 1·35	3rd . . 0·00 = Q
5th . . ·20	4th . . 0·00	
2)2·45	1·35 = P	
1·22 = $\frac{A}{2}$	2	
	2·70 = 2 P	
	1·22 = $\frac{A}{2}$	
	0·00 = Q	
	3·92 = $\frac{A}{2}$ + 2 P + Q	

the depth being equal to 2·1 ft., and the number of equal divisions being taken as two, giving 3 as the number of ordinates, the spaces between the ordinates will be equal to $\frac{2·1}{2} = r$ of the formula, whence $\frac{2r}{3} = \frac{\frac{2·1}{2} \times 2}{3}$, or $\frac{2r}{3}$ will equal $\frac{\text{whole depth}}{3} = \frac{2·1}{3} = ·7$ feet.

With five ordinates, under the same rule, $\frac{2r}{3}$ will equal $\frac{\text{whole depth}}{6}$, with seven ordinates $\frac{2r}{3} = \frac{\text{whole depth}}{9}$.

3·92 = $\frac{A}{2}$ + 2 P + Q	
·7 = $\frac{2r}{3}$	
2·744 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = $\frac{1}{3}$	Area of Vertical Section 2.

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Half Area of the Vertical Section 3, when immersed to the depth of *b b*, or 2·4 feet.

3·7
·2
2)3·9
1·95 = $\frac{A}{2}$

3·0
1·15
4·15 = P
2
8·30 = 2 P
1·95 = $\frac{A}{2}$
2·15 = Q
12·40 = $\frac{A}{2}$ + 2 P + Q
·4 = $\frac{2r}{3}$
4·96 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = ⅔ Area of the Vertical Section 3.

2·15 = Q
6)2·4 = depth at 3.
·4 = $\frac{2r}{3}$

Half Area of the Vertical Section 4, when immersed to the depth of *b b*, or 2·75 feet.

5·0
·25
2)5·25
2·62 = $\frac{A}{2}$

4·0
1·5
5·5 = P
2
11·00 = 2 P
2·62 = $\frac{A}{2}$
2·80 = Q
16·42 = $\frac{A}{2}$ + 2 P + Q
·46 = $\frac{2r}{3}$
9852
6568
7·5532 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = ½ Area of Vertical Section 4.

2·8 = Q
6)2·75 = depth at 4.
·46 = $\frac{2r}{3}$

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Half Area of the Vertical Section 5, when immersed to the depth of *b b*, or 3·1 feet.

5·4
·25
2)5·65
2·82 = $\frac{A}{2}$

4·5
1·55
6·05 = P
2
12·10 = 2 P
2·82 = $\frac{A}{2}$
3·10 = Q
18·02 = $\frac{A}{2}$ + 2 P + Q
·516 = $\frac{2r}{3}$
10812
1802
9010
9·29832 = $\frac{A}{2}$ + 2P + Q × $\frac{2r}{3}$ = ½ Area of Vertical Section 5.

3·1 = Q

6)3·10 = depth at 5.
·516 = $\frac{2r}{3}$

Half Area of the Vertical Section 6, when immersed to the depth of *b b*, or 3·5 feet.

4·3
·2
2)4·5
2·25 = $\frac{A}{2}$

3·6
1·1
4·7 = P
2
9·4 = 2 P
2·25 = $\frac{A}{2}$
2·10 = Q
13·75 = $\frac{A}{2}$ + 2 P + Q
·58 = $\frac{2r}{3}$
11000
6875
7·9750 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = ½ Area of Vertical Section 6.

2·1 = Q

6)3·5 = depth at 6.
·58 = $\frac{2r}{3}$

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Half Area of the Vertical Section 8, when immersed to the depth of $b\,b$, or 4·2 feet.

2·05	1·05	·60 = Q
·20	·35	
2)2·25	1·40 = P	
1·12 = $\frac{A}{2}$	2	
	2·80 = 2 P	
	1·12 = $\frac{A}{2}$	
	·60 = Q	
	4·52 = $\frac{A}{2}$ + 2 P + Q	
	·7 = $\frac{2r}{3}$	
	3·164 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = ½ Area of Vertical Section 8.	

6)4·2 = depth at 8.
·7 = $\frac{2r}{3}$

Formation of the curve G D L, by these areas, or the delineation of the curve G D L of the curves of sectional areas, Plate C, as the representative area of the zone of displacement to the immersion $b\,b$, the depth of the zone being taken as three feet. The points L and G in the base A B, which form the endings of the curve G D L, are obtained from Fig. 8, Plate A, by squaring down the intersections of the line $b\,b$, with the fore-edge of the rabbet of the stem, and after-edge of the rabbet of the stern-post, the line A B being the length of the load-water line; under similar limits, therefore, L G equals the length of the water $b\,b$, of Fig. 8, Plate A.

Distinguishing Number of the Vertical Sections.	Half Areas of the Vertical Sections. Feet.	Divisor.	Ordinates for the Curve of Sections.
2	2·744	3	·914
3	4·916		1·638
4	7·553		2·517
5	9·298		3·10 = F D
6	7·975		2·658
8	3·164		1·054

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Results obtained from the Curve of Sectional Areas formed on the base L G.

Length of the water line $b\,b = 42{\cdot}8$ ft. whence $F\,L = F\,G = \frac{b\,b}{2} = 21{\cdot}4$ ft.

Area of the Fore Triangle $F\,D\,L = \frac{F\,L \times F\,D}{2} = \frac{21{\cdot}4 \times 3{\cdot}1}{2}$.

Zone under the Area $D\,F\,L = \frac{F\,L \times F\,D}{2} \times 3 = \frac{21{\cdot}4 \times 3{\cdot}1}{2} \times 3 =$ 99·51 cubic feet of space.

Area of the After Triangle $F\,D\,G = \frac{F\,D \times F\,G}{2} = \frac{3{\cdot}1 \times 21{\cdot}5}{2}$.

Zone under the Area $D\,F\,G = \frac{F\,D \times F\,G}{2} \times 3 = \frac{3{\cdot}1 \times 21{\cdot}5}{2} \times 3 =$ 99·96 cubic feet of space.

Fore Hypothenuse $D\,L = \sqrt{\overline{L\,F}^2 + \overline{D\,F}^2} = \sqrt{\overline{21{\cdot}4}^2 + \overline{3{\cdot}1}^2} = \sqrt{467{\cdot}57} = 21{\cdot}62$ feet.

Fore Parabolic Area contained under the hypothenuse D L and the curve = D L $\times \frac{2}{3}$ of the maximum perpendicular on D L = 21·62 $\times \frac{2}{3}$ of ·3.

Zone under that area = 21·62 $\times \frac{2}{3}$ of ·3 × 3 = 12·972 cubic feet of space.

After Hypothenuse $D\,G = \sqrt{\overline{F\,G}^2 + \overline{D\,F}^2} = \sqrt{\overline{21{\cdot}5}^2 + \overline{3{\cdot}1}^2} = \sqrt{471{\cdot}86} = 21{\cdot}72$ feet.

After Parabolic Area contained under the Hypothenuse D G and the curve is equal to D G $\times \frac{2}{3}$ of the maximum perpendicular on D G = 21·72 $\times \frac{2}{3}$ of ·5.

Zone under that Area = 21·72 $\times \frac{2}{3}$ of ·5 × 3 = 21·72 cubic feet of space.

Whence, for the Half Displacement to the Immersion *b b*.

	Cubic Feet.
Fore Zone under the Fore Triangle F D L	= 99·51
After Zone „ „ After „ F D G	= 99·96
Fore Zone under the Parabolic Area .	= 12·97
After Zone „ „ „ „ .	= 21·72
	5)234·16 cubic ft.
	7)46·83
	6·69 =

Half Displacement in tons of 35 cubic feet of space, and 6·69 × 2 = 13·38 tons = Displacement under the immersion *b b*.

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Displacement to the assumed Immersion *d d*, Fig. 8, Plate A.

Half Area of the Vertical Section 3 to the depth of *d d*, or ·65, considered to be a Triangle.

		feet.
Base or Breadth of the Horizontal Section *d d* at 3, as shown on the Half-breadth Plan, Fig. 8, Plate A . . .	=	1·15
Depth at 3, taken from the Sheer Plan, Fig. 8, Plate A .	=	·65
		575
		690
Product of these two .	=	7·475

Which, divided by 2, gives 3·73 feet for the Half Area of the Vertical Section 3, under the immersion *d d*.

Vertical Section 4.

Considered as a Triangle, then the

		feet.
Base as similarly taken for (3) . . .	=	2·0
Depth „ „	=	1·0
Product of these quantities	=	2·0

Which, divided by 2, gives 1·0 foot for the Half Area of the Vertical Section 4, under the immersion *d d*.

Half Area of the Vertical Section 5, when immersed to the depth *d d*, or 1·35 feet.

2·65
·20
2)2·85
1·42 = $\frac{A}{2}$

2·15
1·00
3·15 = P
2
6·30 = 2 P
1·42 = $\frac{A}{2}$
1·50 = Q
9·22 = $\frac{A}{2}$ + 2 P + Q

1·5 = Q

6)1·35 = depth at 5.
·22 = $\frac{2r}{3}$

·22 = $\frac{2r}{3}$

1844
1844
2·0284 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = { ½ Area of Vertical Section 5, under the immersion *d d*.

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Half Area of the Vertical Section 6, when immersed to the depth *d d*, or 1·7 feet.

2·05
·20
2)2·25
1·12 = $\frac{A}{2}$

1·55
·60
2·15 = P
2
4·30 = 2 P
1·12 = $\frac{A}{2}$
1·00 = Q
6·42 = $\frac{A}{2}$ + 2 P + Q
·283 = $\frac{2r}{3}$
1926
5136
1284
1·81686 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = { ½ Area of Vertical Section 6, under the immersion *d d*.

1·00 = Q

6)1·7 = depth at 6.
·283 = $\frac{2r}{3}$

Half Area of the Vertical Section 8, when immersed to the depth *d d*, or 2·4 feet.

·75
·20
2)·95
·475 = $\frac{A}{2}$

·55
·30
·85 = P
2
1·70 = 2 P
·475 = $\frac{A}{2}$
·400 = Q
2·575 = $\frac{A}{2}$ + 2 P + Q
·4 = $\frac{2r}{3}$
1·0300 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = { ½ Area of Vertical Section 8, under the immersion *d d*.

·4 = Q

6)2·4 = depth at 8.
·4 = $\frac{2r}{3}$

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Distinguishing Number of the Vertical Sections.	Half Areas of the Vertical Sections. Feet.	Divisor.	Ordinates for the Curve of Sections.
3	·7475	1	·74
4	1·0000		1·0
5	2·0280		2·02 = F E
6	1·8168		1·80
8	1·0300		1·03

Results from the Curve of Sectional Areas formed by these Ordinates, considered as circumscribing an Area representative of the Half Displacement under the immersion *d d* of Fig. 8, Plate A.

Plate C.

Length of the load-water line at the immersion *d d* = 39·35 F K = 18·5 and H F = 20·85 feet.

Area of the Fore Triangle F E K = $\frac{\text{F K} \times \text{F E}}{2} = \frac{18{\cdot}5 \times 2{\cdot}02}{2}$.

Solid, or Zone, under such Area = $\frac{\text{K F} \times \text{F E}}{2} \times 1 = \frac{18{\cdot}5 \times 2{\cdot}02}{2} \times 1$ = 18·685 cubic feet.

Area of the After Triangle H F E = $\frac{\text{H F} \times \text{F E}}{2} = \frac{20{\cdot}85 \times 2{\cdot}02}{2}$.

Solid, or Zone, under such Area = $\frac{\text{H F} \times \text{F E}}{2} \times 1 = \frac{20{\cdot}85 \times 2{\cdot}02}{2} \times 1$ = 21·058 cubic feet.

After Hypothenuse H E = $\sqrt{\text{H F}^2 + \text{F E}^2} = \sqrt{\overline{20{\cdot}85}^2 + \overline{2{\cdot}02}^2} = \sqrt{438{\cdot}8} = 20{\cdot}95$.

After Parabolic Area = E H × $\frac{2}{3}$ of the maximum perpendicular on E H = 20·95 × $\frac{2}{3}$ of ·6.

After Zone, or Solid, under that Area = 20·95 × $\frac{2}{3}$ of ·6 × 1 = 8·380 cubic feet.

By measurement with a scale of equal parts, the Hypothenuse for the Fore Parabolic Area equals 15·8 feet.

Whence Fore Parabolic Area = 15·8 × $\frac{2}{3}$ of ·5; where ·5 is the maximum perpendicular on the hypothenuse.

Fore Zone, or Solid, under that Area = 15·8 × $\frac{2}{3}$ of ·5 × 1 = 5·26 cubic feet.

The division of the curve of sectional areas into four portions, viz., two triangles and two parabolic areas, points out, in

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this case, that the fore triangular area exceeds the area required by the fore parabolic area, and that thence the solid will be under a similar excess; in summing these portions for the amount of half displacement, the solid under the fore parabolic area must be subtracted from the sum of the three other portions, or the half displacement under the immersion, *d d* will be obtained from the foregoing calculations by adding together the following:

	Cubit Feet of Space.
Zone, or Solid, under Fore Triangle . . . =	18·685
„ „ „ After „ . . . =	21·058
„ „ under After Parabolic Area . . =	8·380
	48·123
And subtracting	
Zone, or Solid, under the Fore Parabolic Area . =	5·260
	42·863 =

Half Displacement in cubic feet of space to the immersion *d d*; whence

42·863 × 2 = 85·726 = whole Displacement in cubic feet of space due to the immersion *d d*.

which, divided by 35, or 5)85·726

7)17·145

2·45 gives 2·45 tons Displacement to the immersion *d d*.

Under these results, to form a scale for tonnage, proceed as described in page 23, by assuming C D on the scale of tons, Plate C, as a line of scale for depth or mean draught of water, the lower part of which, D, is at the same depth as the underside of the false keel of the vessel amidships, and delineate on this line, C D, a scale of parts; on this scale set off the midships depths of the calculated immersions, or those at 55 section, Fig. 8, Plate A; draw lines at the points thus obtained perpendicular to this scale of depth, as F G, H I, K L, M N, and draw E A parallel to C D, the lower point E being considered as at the depth of the underside of the false keel, and thence on a level with the point D of the scale of parts; from the point A in E A (assumed as convenient) draw a line A B parallel to F G, and on it form a scale of equal parts for tons,

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as shown in the scale for tonnage, Plate C, to be numbered to 32 tons: in this Fig., F E corresponds to the immersion A B at 55, or amidships, H E, to the immersion of *b b* at 55, or amidships, K E, to the immersion of *d d* at 55 or amidships, and M E to the immersion of the keel: the calculated displacements due to these respective immersions are as follow:—

To the immersion for A B, or Load-water Line						.	.	30·88 Tons.
,,	,,	,,	*b b*	,,	2nd	,,	.	.	13·98 ,,
,,	,,	,,	*d d*	,,	3rd	,,	.	.	2·45 ,,
,,	,,	,,	of the keel		,,	,,	.	.	·66 ,,

These displacements are set off on the scale A B, as shown in the Fig., Plate C.

Where A R = 30·88
A Q = 13·98
A P = 2·45
A O = ·66
} parts of the Scale of Tons;

and the points R, Q, P, and O, thus determined, are squared down to meet the lines F G, H I, K L, and M N, drawn square to the line C D in the points G, I, L, and M, when a curve, passed through those points, will form a scale of tons for the displacement to any assumed or real immersion considered as the midship immersion; thus, should the displaced volume or tonnage be required at a mean immersion of 5 feet, a line must be drawn from 5 on the scale for the mean draught of water amidship, Plate C, parallel to F G, to meet the curve E N L I G in some point S, which point S being squared up to the scale for tons, will cut the scale in the point V, as denoting 19·8 tons, which will be the volume due to that immersion; the same for any other point of required immersion, and thence, conversely, may be determined the increased draught of water the vessel would draw on additional weights being placed in her. The yacht being at a mean draught of water amidships of 4·3 feet, it is required the additional immersion that will ensue from her taking on board six tons of ballast; at 4·3 feet immersion, the scale, Plate C, gives A Q on the

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line denoting the tonnage, or 13·98 tons; to which, if the six tons required to be placed on board be added, the sum will be 19·98 tons, which will give the point V, on the scale for tons, which point squared down gives the point S in the curve E N L I G; and that point being transferred to the scale C D, gives 5 feet as the immersion which the increased weight placed on board will cause, or that six tons would at the mean draught of water of 4·3 feet, immerse the vessel bodily ·7 feet, or $8\frac{1}{2}$ inches nearly. A similar process will give the weight required to be taken out of the vessel, to bring her up to any given or assumed draught of water; as, from 5 feet to 4·3 feet, which would involve a process the converse of that given for the addition of six tons.

PART XVII.

An Example of the Comparison of the Forms of Ships, by the Curve of Sections being applied to the Vertical Sections of her Majesty's Ship Vanguard, of the Year 1835, and the French Canopus, of the Year 1786; and a further Application of the Curve of Sectional Areas to the Light and Load Displacements of the same Men of War; with a view of showing their relative Capacities for carrying Weights, and to facilitate their Stowage, as pointed out in page 17.

THE Plate D is descriptive of the longitudinal sections of the ships, the athwartship vertical sections being thrown down on them at their respective stations, to show the forms of the ships, the curves or form of them being to the outside of the plank of the bottom. The areas to the water lines for light and load-water displacements are then measured by Rule 1, as follows:—A B being the load-water line, and D C the light-water line, of H. M. S. Vanguard.

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VANGUARD.—LOAD DISPLACEMENT.

Midship Section, or Vertical Section 3, Plate D.

27·8
·8
2)28·6
14·3 = $\frac{A}{2}$

26·9
23·8
17·6
7·2
75·5 = P
2
151·0 = 2 P
14·3 = $\frac{A}{2}$
60·0 = Q
225·3 = $\frac{A}{2}$ + 2 P + Q
1·8 = $\frac{2r}{3}$
18024
2253
405·54 = $\sqrt{\frac{A}{2} + 2P + Q \times \frac{2r}{3}}$ = { ½ Area of Midship Section when immersed to the load draught of water, A B.

25·6
21·2
13·2
60·0 = Q

12)21·6 = { depth of 3.
1·8 = $\frac{2r}{3}$

Vanguard. Vertical Section 2, Plate D.

27·2
·8
2)28·0
14·0 = $\frac{A}{2}$

27·0
24·2
18·4
8·0
77·6 = P
2
155·2 = 2 P
61·8 = Q
14·0 = $\frac{A}{2}$
231·0 = $\frac{A}{2}$ + 2 P + Q
1·78 = $\frac{2r}{3}$
1848
1617
231
411·18 = $\sqrt{\frac{A}{2} + 2P + Q \times \frac{2r}{2}}$ = { ½ Area of Vertical Section 2, when immersed to the load draught of water, A B.

26·0
21·8
14·0
61·8 = Q

12)21·4 = { depth of 2.
1·78 = $\frac{2r}{3}$

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Vanguard. Vertical Section 1, Plate D.

25·4	23·8	22·0	12)21·2 = { depth of 1
·8	19·4	16.04	
	12·80	9·2	1·76 = $\frac{2r}{3}$
2)26·2	5·20		
		47·24 = Q	
13·1 = $\frac{A}{2}$	61·20 = P		
	2		
	122·4 = 2 P		
	13·1 = $\frac{A}{2}$		
	47·24 = Q		
	182·74 = $\frac{A}{2}$ + 2 P + Q		
	1·76 = $\frac{2r}{3}$		
	109644		
	127918		
	18274		
	321·6224 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = { ½ Area of Vertical Section 1, when immersed to the load draught of water, A B.		

Vanguard. Vertical Section 4, Plate D.

27·2	26·4	25·2	12)22·0 = { depth of 4.
·80	22·8	19·6	
	15·8	11·2	1·83 = $\frac{2r}{3}$
2)28·00	6·2		
		56·0 = Q	
14·00 = $\frac{A}{2}$	71·2 = P		
	2		
	142·4 = 2 P		
	14·0 = $\frac{A}{2}$		
	56·0 = Q		
	212·4 = $\frac{A}{2}$ + 2 P + Q		
	1·83 = $\frac{2r}{3}$		
	6372		
	16992		
	2124		
	388·692 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = { ½ Area of Vertical Section 4, when immersed to the load draught of water, A B.		

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Vanguard. Vertical Section 5, Plate D.

24·60	23·00	20·20	12)22·20 = { depth of 5.
·80	16·20	12·80	
	8·80	5·80	1·85 = $\frac{2r}{3}$
2)25·40	3·00		
		38·80 = Q	
12·7 = $\frac{A}{2}$	51·00 = P		
	2		
	102·00 = 2 P		
	12·70 = $\frac{A}{2}$		
	38·80 = Q		
	153·50 = $\frac{A}{2}$ + 2 P + Q		
	1·85 = $\frac{2r}{3}$		
	7675		
	12280		
	1535		
	283·975 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{2}$ = { ½ Area of Vertical Section 5, when immersed to the load draught of water, A B.		

From these half areas, the curve E G F of sectional areas, forming the representative area for the zone of half displacement, is formed in the following manner: take E F, Plate D, parallel to the lower edge of keel, and equal in length to where the load-water A B of Vanguard cuts the fore edge of the rabbet of the stem and after edge of the rabbet of the post, and to the line A B square down the positions of the vertical sections 1, 2, 3, 4, and 5, of the Sheer Plan, Plate D; then for the representative ordinates of the curve of sections to the load-displacement at those stations, we have the following estimated data:—

Distinguishing Number of the Vertical Sections.	Half Area of Vertical Sections.	Divisor.	Ordinates for Curve. Feet.
1	321·62	30	10·72
2	411·18		13·706
3	405·54		13·518 = H G
4	388·69		12·956
5	283·97		9·465

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which ordinates are set off from E F on their respective stations 1.1, 2.2, 3.3, 4.4, and 5.5, giving the points for the curve E G F, and the area E G F bounded by that curve and the line E F. E F by measurement = 186 ft., whence E H and F H are equal to $\frac{186}{2} = 93$ ft., and the whole area E G F when divided into the four portions; the triangle F H G, triangle E H G, parabolic area under the hypothenuse G F, and the parabolic area under the hypothenuse G E, can be thus numerically determined:—

Area of the Triangle F H G = Area of Triangle E H G = $\frac{\text{E H} \times \text{H G}}{2}$; whence the sum of the Areas F H E and E H G = E H × H G.

Or, the Areas of the Triangles F H G + E H G = E H × H G = 93·0 ft. × 13·518.

And Solid, or Zone, under such Area = 93·0 × 13·518 × 30 = 37715·220 cubic feet of space.

Hypothenuse E G or F G = $\sqrt{\text{E H}^2 + \text{H G}^2} = \sqrt{\overline{93{\cdot}0}^2 + \overline{13{\cdot}52}^2} =$

$\sqrt{8649{\cdot}0 + 182{\cdot}79} = \sqrt{8831{\cdot}79} = 93{\cdot}97$ feet.

Area G K F G = $\frac{2}{3}$ F G × maximum perpendicular on F G, (p. 61,) = $\frac{2}{3}$ of 93·97 × 6·0.

Solid, or Zone, under the Area G K F G } = $\frac{2}{3}$ of F G × maximum perpendicular on F G × 30 = 2 × 93·97 × 6·0 × 10 = 11276·4 cubic feet of space.

Area E L G E = $\frac{2}{3}$ of E G × maximum perpendicular on E G, (p. 61,) = $\frac{2}{3}$ of 93·97 × 4·6.

Solid, or Zone, under the Area E L G E } = $\frac{2}{3}$ of E G × maximum perpendicular on E G × 30 = 2 × 93·97 × 4·6 × 10 = 8645·24 cubic feet of space.

From which is obtained the following summary for the displacement to the immersion A B, or load line of the Vanguard.

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Solid or Zone under the Areas F H G + E H G in cubic feet of space	= 37715·22
Solid or Zone under the Fore Parabolic Area G K F G in cubic feet of space	= 11276·40
Solid or Zone under the After Parabolic Area E L G E in cubic feet of space	= 8645·24
Divided by 35· as the number of cubic feet equal to a Ton.	5)57636·86
	7)11527·37
	1646·76 Tons.

= ½ Displacement of Vanguard, and 1646·76 × 2 = 3293·52 Tons = whole Displacement to a draught of Water { Afore . . 23·0 ft. / Aft . . 24·0

Light Displacement of Vanguard by the Curve of Sectional Areas, and Zone for the Solid to the Draught of Water.

Afore . . . = 16·25 feet.
Aft . . . = 18·5 „

Half Area of Vertical Section 1.

20·8	18·2	15·2	9)14·8 = depth
·8	12·0	8·4	1·64 = $\frac{2r}{3}$
2)21·6	4·6	23·6 = Q	
10·8 = $\frac{A}{2}$	34·8 = P		
	2		
	69·6 = 2 P		
	10·8 = $\frac{A}{2}$		
	23·6 = Q		
	104·0 = $\frac{A}{2}$ + 2 P + Q		
	1·64 = $\frac{2r}{3}$		
	416		
	624		
	104		
	170·56 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ =		½ Area of Vertical Section 1, when immersed to the light draught of water D C.

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Half Area of Vertical Section 2.

25·2	23·4	20·8	9)15·4 = depth
·8	17·6	13·4	1·7 = $\frac{2r}{3}$
2)26·0	8·2	34·2 = Q	
13·0 = $\frac{A}{2}$	49·2 = P		
	2		
	98·4 = 2 P		
	13·0 = $\frac{A}{2}$		
	34·2 = Q		
	145·6 = $\frac{A}{2}$ + 2 P + Q		
	1·7 = $\frac{2r}{3}$		
	10192		
	1456		
	247·52 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ =		½ Area of Vertical Section 2, when immersed to the light draught of water.

Half Area of Vertical Section 3.

25·8	23·6	20·6	9)16 = depth
·8	17·0	12·0	1·8 = $\frac{2r}{3}$
2)26·6	7·0	32·6 = Q	
13·3 = $\frac{A}{2}$	47·6 = P		
	2		
	95·2 = 2 P		
	13·3 = $\frac{A}{2}$		
	32·6 = Q		
	141·1 = $\frac{A}{2}$ + 2 P + Q		
	1·8 = $\frac{2r}{3}$		
	11288		
	1411		
	253·98 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ =		½ Area of Vertical Section 3, when immersed to the light draught of water.

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Half Area of Vertical Section 4.

25·2
·8
2)26·0
13·0 = $\frac{A}{2}$

23·2
16·0
6·2
45·4 = P
2
90·8 = 2 P
13·0 = $\frac{A}{2}$
31·4 = Q
135·2 = $\frac{A}{2}$ + 2 P + Q
1·82 = $\frac{2r}{3}$
2704
10816
1352
246·064 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = ½ Area of Vertical Section 4, when immersed to the light draught of water.

20
11·4
31·4 = Q

9)16·40 = depth of Section.
1·82 = $\frac{2r}{3}$

Half Area of Vertical Section 5.

20·4
·8
2)21·2
10·6 = $\frac{A}{2}$

17·4
9·8
3·4
30·6 = P
2
61·2 = 2 P
10·6 = $\frac{A}{2}$
19·8 = Q
91·6 = $\frac{A}{2}$ + 2 P + Q
1·86 = $\frac{2r}{3}$
5496
7328
916
170·376 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = ½ Area of Vertical Section 5, when immersed to the light draught of water.

13·6
6·2
19·8 = Q

9)16·8 = depth
1·86 = $\frac{2r}{2}$

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From these half areas, the curve N M O of sectional areas, forming the representative area for the zone of the half-light displacement, is formed in the following manner:—square down the points N and O to the line E F, such points being where the light-water line D C, in the Sheer Plan, Plate D, cuts respectively the after edge of the rabbet of the stern post and fore edge of the rabbet of the stem, the positions of the vertical sections 1, 2, 3, 4, and 5, remaining the same as for the load displacement; then, for the representative ordinates to the curve of sections to the light displacement at those stations, we have the following estimated data.

Distinguishing Number of the Vertical Sections.	Half Areas of the Vertical Sections. Superficial Feet.	Divisor.	Ordinates for the Curve.
1	170·56	30	5·68
2	247·52		8·25
3	253·98		8·46 = H m
4	246·06		8·20
5	170·37		5·67

which ordinates are set off from the base E F, Plate D, on the respective stations, as 11′, 22′, 33′, 44′, and 55′, giving the points for the curve N M O, and the area N M O bounded by that curve and the base N O, part of the base E F. N O, being equal to the length of the light-water section C D, is equal by measurement to 182·8 feet, of which the fore length H O = 90·0 ft., whence N H = N O − H O = 182·8 ft. − 90 = 92·8 feet; and the area N M O, when divided into the four portions, the triangle H M O, the triangle H M N, the parabolic area under the hypothenuse M O, and the parabolic area under the hypothenuse M N, can be numerically determined as follows:—

$$\text{Area of the Triangle H M O} = \frac{\text{O H} \times \text{M H}}{2} = \frac{90 \times 8{\cdot}46}{2} = 380{\cdot}7.$$

$$\text{Solid or Zone under such Area} = \frac{\text{O H} \times \text{M H}}{2} \times 30 = \frac{90 \times 8{\cdot}46}{2} \times 30 = 11421{\cdot}0.$$

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Area of the Triangle H M N $= \frac{N H \times H M}{2} = \frac{92{\cdot}8 \times 8{\cdot}46}{2} = 392{\cdot}544.$

Solid or Zone under such Area $= \frac{N H \times H M}{2} \times 30 = \frac{92{\cdot}8 \times 8{\cdot}46}{2} \times 30$
$= 11776{\cdot}3.$

Fore Hypothenuse M O $= \sqrt{O H^2 + H M^2} = \sqrt{\overline{90}^2 + \overline{8{\cdot}46}^2} =$
$\sqrt{8100 + 71{\cdot}57} = \sqrt{8171{\cdot}57} = 90{\cdot}4$ feet.

The Fore Parabolic Area M P O M $= \frac{2}{3}$ of M O $\times$ maximum perpendicular on M O. (Page 61.)

Solid or Zone under the Area M P O M $= \frac{2}{3}$ of M O $\times$ maximum perpendicular on M O $\times$ 30 $= \frac{2}{3}$ of $90{\cdot}4 \times 2{\cdot}8 \times 30 = 5062{\cdot}4$ cubic ft.

After Hypothenuse M N $= \sqrt{\overline{N H}^2 + \overline{H M}^2} = \sqrt{\overline{92{\cdot}8}^2 + \overline{8{\cdot}46}^2} =$
$\sqrt{8611{\cdot}84 + 71{\cdot}57} = \sqrt{8683{\cdot}41} = 93{\cdot}2$ feet.

The After Parabolic Area N Q M N $= \frac{2}{3}$ of N M $\times$ maximum perpendicular on M N. (Page 61.)

Solid or Zone under the Area M Q M N $= \frac{2}{3}$ of M N $\times$ maximum perpendicular on M N $\times$ 30 $= \frac{2}{3}$ of $93{\cdot}2$ ft. $\times 2{\cdot}6 \times 30 = 4846{\cdot}4$ cubic ft.

	Cubic feet of Space.
Solid or Zone under the Fore Triangular Area H M O	= 11421·0
Solid or Zone under the After Triangular Area H M N	= 11776·3
Solid or Zone under the Fore Parabolic Area M P O M	= 5062·4
Solid or Zone under the After Parabolic Area N Q M N	= 4846·4
	5)33106·1
	7)6621·22
	945·89 = ½ Light
	2 Displacement in
Light Displacement in Tons of Medium Water of 35 Cubic Feet to the Ton .	= 1891.78 Tons.

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Canopus of 1786.

Load Displacement to a Draught of Water of . . . . . { Afore = 22·0 ft. / Aft. = 24·5 ft. } Plate D.

Half Area of Vertical Section 3.

26·0	25·6	25·0	12)20·8 = depth
·80	24·0	22·8	1·73 = $\frac{2r}{3}$
	20·8	17·6	
2)26·80	12·6	65·4 = Q	
13·40 = $\frac{A}{2}$	83·0 = P		
	2		
	166·0 = 2 P		
	13·4 = $\frac{A}{2}$		
	65·4 = Q		
	244·8 = $\frac{A}{2}$ + 2 P + Q		
	1·73 = $\frac{2r}{3}$		
	7344		
	17136		
	2448		
	423·504 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ =		½ Area of Vertical Section 3 to the depth of the load-water line.

Half Area of Vertical Section 2.

25·40	25·00	24·20	12)20·6 = depth
·80	23·40	22·20	1·71 = $\frac{2r}{3}$
	20·20	17·20	
2)26·2	12·20	63·60 = Q	
13·1 = $\frac{A}{2}$	80·80 = P		
	2		
	161·60 = 2 P		
	13·1 = $\frac{A}{2}$		
	63·60 = Q		
	238·30 = $\frac{A}{2}$ + 2 P + Q		
	1·71 = $\frac{2r}{3}$		
	2383		
	16681		
	2383		
	407·493 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ =		½ Area of Vertical Section 2 to the depth of the load-water line.

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Half Area of Vertical Section 1.

24·0	22·8	21·2	12)20·4 = depth
·8	18·8	16·6	1·7 = $\frac{2r}{3}$
	13·4	9·8	
2)24·8	5·6		
12·4 = $\frac{A}{2}$	60·6 = P	47·6 = Q	
	2		
	121·2 = 2 P		
	12·4 = $\frac{A}{2}$		
	47·6 = Q		
	181·2 = $\frac{A}{2}$ + 2 P + Q		
	1·7 = $\frac{2r}{3}$		
	12684		
	1812		
	308·04 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ =		½ Area of Vertical Section 1 to the depth of the load-water line.

Half Area of Vertical Section 4.

25·2	25·0	24·2	12)21·0 = depth
·8	22·8	20·8	1·75 = $\frac{2r}{3}$
	18·0	14·4	
2)26·0	9·4		
13·0 = $\frac{A}{2}$	75·2 = P	59·4 = Q	
	2		
	150·4 = 2 P		
	13·0 = $\frac{A}{2}$		
	59·4 = Q		
	222·8 = $\frac{A}{2}$ + 2 P + Q		
	1·75 = $\frac{2r}{3}$		
	11140		
	15596		
	2228		
	389·900 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ =		½ Area of Vertical Section 4 to the depth of the load-water line.

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Half Area of Vertical Section 5.

23·6	22·8	20·6	12)21·52 = depth
·8	15·6	11·4	1·8 = $\frac{2r}{3}$
2)24·4	8·0	5·0	
12·2 = $\frac{A}{2}$	2·4	37·0 = Q	
	48·8 = P		
	2		
	97·6 = 2 P		
	12·2 = $\frac{A}{2}$		
	37·0 = Q		
	146·8 = $\frac{A}{2}$ + 2 P + Q		
	1·8 = $\frac{2r}{3}$		
	11744		
	1468		
	264·24 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ =		½ Area of the Vertical Section 5, when immersed to the load-water line.

ft. in.

From the data given by the foregoing Vertical Areas, the curve of Sectional Areas and Zone for the Load Displacement of H.M. Ship Canopus, to the Draught of Water of Afore . = 22 ,, 0

Ditto . . . . . Aft . . = 24 ,, 6

may be formed.

Distinguishing Number of the Vertical Sections.	Half Areas of the Vertical Sections. Superficial Feet.	Divisor.	Ordinates for the Curve of Sections.
1 . .	308·00 . .	30 . .	10·26
2 . .	407·49 . .	. .	13·58
3 . .	423.5 . .	. .	14·12 = *f c*
4 . .	389·9 . .	. .	12.99
5 . .	264·24 . .	. .	8·80

From these ordinates the curve of sectional areas, *a, b, c, d, e,* for the load-displacement can be delineated for the Canopus as directed for the formation of a similar curve for the Vanguard; the extremes of the curve being as before, the limits of the load-water line of the ship squared down to the base *a e*. To measure the representative area, *a, b, c, d, e, f, a*; *f c* being the medial

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section; divide it into four portions, the triangles $a\,c\,f$ and $f\,c\,e$, and the parabolic areas contained under the hypothenuses, $a\,c$, $c\,e$, and the curve. To estimate the numerical values of these areas, we have

Length of load-water line = 193·2 feet;

whence $af = fe = \frac{193{\cdot}2}{2}$ feet = 96·6 feet, and $f\,c$, is by calculation equal to 14·12 feet.

Area of fore representative triangle $cfe = \frac{fe \times fc}{2} = \frac{96{\cdot}6 \times 14{\cdot}12 \text{ ft.}}{2}$

$= \frac{1363{\cdot}992}{2} = 681{\cdot}996.$

Solid under such area $= \frac{fe \times fc}{2} \times 30 = \frac{96{\cdot}6 \times 14{\cdot}12}{2} \times 30 =$

$\frac{1363{\cdot}992}{2} \times 30 = 20459{\cdot}88$ cubic feet of space.

After triangular representative area $a\,c\,f = \frac{af \times fc}{2}$ solid $= \frac{fe \times fc}{2}$

$\times 30 = 20459{\cdot}88$ cubic feet of space.

The hypothenuse $c\,e = a\,c = \sqrt{af^2 + fc^2} = \sqrt{\overline{96{\cdot}6}^2 + \overline{14{\cdot}12}^2} =$

$\sqrt{9331{\cdot}56 + 199{\cdot}37} = \sqrt{9530{\cdot}9} = 97{\cdot}6$ feet.

Fore parabolic area $c\,d\,e\,c = c\,e \times \frac{2}{3}$ of the maximum perpendicular on $c\,e$ $= 97{\cdot}6 \times \frac{2}{3}$ of 5·4.

Zone or solid under such area $= c\,e \times \frac{2}{3}$ of the maximum perpendicular on $c\,e \times 30 = 97{\cdot}6 \times \frac{2}{3}$ of $5{\cdot}4 \times 30 = 10540{\cdot}8$ cubic feet of space.

After parabolic area $a\,b\,c\,a = a\,c \times \frac{2}{3}$ of the maximum perpendicular on $a\,c$ $= 97{\cdot}6 \times \frac{2}{3}$ of 4·2.

Zone or solid under such area $= a\,c \times \frac{2}{3}$ of the maximum perpendicular on $a\,c \times 30 = 97{\cdot}6 \times \frac{2}{3}$ of $4{\cdot}2 \times 30 = 8198{\cdot}4$.

		ft.	in.	
From which the half load displacement of the draught of water of	Canopus to Afore	22	0	is as follows.
Ditto	Aft	24	6	

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		Cubic Feet.
Solid from the triangles *c f e*, *c f a*	= 20459·88 × 2	= 40919·76
„ fore parabolic *c d e c*	. .	= 10540·80
„ after „ *a b c a*	. .	= 8198·40
		5)59658·96
		7)11931·79
Tons.		
or 1704·54 = ½ displacement		1704·54
2		
3409·08 = load displacement of Canopus to	Afore	22 ft. 0 in.
„ „ „	Aft	24 ft. 6 in.

Light Displacement of H. M. Ship Canopus by the Curve of Sectional Areas and Zone for the solid to the Draught of Water.

	ft.	in.
Afore . . .	= 14	„ 3
Aft . . .	= 18	„ 9

Half Area of Vertical Section 1.

19·6	17·8	15·4	9)13·6 = de
·8	12·4	9·4	$1{\cdot}51 = \frac{2r}{3}$
2)20·4	5·8	24·8 = Q	
$10{\cdot}2 = \frac{A}{2}$	36·0 = P		
	2		
	72·0 = 2 P		
	$10{\cdot}2 = \frac{A}{2}$		
	24·8 = Q		
	$107{\cdot}0 = \frac{A}{2} + 2P + Q$		
	$1{\cdot}51 = \frac{2r}{3}$		
	107		
	535		
	107		
	$161{\cdot}57 = \frac{A}{2} + 2P + Q \times \frac{2r}{3}$ =	½ Area of the Vertical Section 1, when immersed to the depth of the light-water immersion.	

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Half Area of Vertical Section 2.

24·0
·8
2)24·8
12·4 = $\frac{A}{2}$

23·0
19·6
12·0
54·6 = P
·2
109·2 = 2 P

21·6
17·0
38·6 = Q

9)14·2 = depth
1·58 = $\frac{2r}{3}$

12·4 = $\frac{A}{2}$
38·6 = Q
160·2 = $\frac{A}{2}$ + 2 P + Q
1·58 = $\frac{2r}{3}$

12816
8010
1602
253·116 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = ½ Area of the Vertical Section 2, when immersed to the depth of the light-water immersion.

Half Area of Vertical Section 3.

24·4
·8
2)25·2
12·6 = $\frac{A}{2}$

24·0
20·6
12·6
57·2 = P
2
114·4 = 2 P

22·6
18·4
41·0 = Q

9)15·00 = depth
1·66 = $\frac{2r}{3}$

12·6 = $\frac{A}{2}$
41·0 = Q
168·0 = $\frac{A}{2}$ + 2 P + Q
1·66 = $\frac{2r}{3}$

1008
1008
168
278·88 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = ½ Area of Vertical Section 3, when immersed to the depth of the light-water immersion.

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Half Area of Vertical Section 4.

24·20
·8
2)25·0
12·5 = $\frac{A}{2}$

22·8
18·0
9·4
50·2 = P
2
100·4 = 2 P
12·5 = $\frac{A}{2}$
34·8 = Q
147·7 = $\frac{A}{2}$ + 2 P + Q
1·75 = $\frac{2r}{3}$

20·8
14·0
34·8 = Q

9)15·8 = depth
1·75 = $\frac{2r}{3}$

7385
10339
1477
258·475 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = { ½ Area of Vertical Section 4, when immersed to the depth of the light-water immersion.

Half Area of the Vertical Section 5.

19·6
·8
2)20·4
10·2 = $\frac{A}{2}$

16·0
8·2
2·4
26·6 = P
2
53·2 = 2 P
10·2 = $\frac{A}{2}$
16·6 = Q
80·0 = $\frac{A}{2}$ + 2 P + Q
1·82 = $\frac{2r}{3}$

11·6
5·0
16·6 = Q

9)16·4 = depth
1·82 = $\frac{2r}{3}$

160
640
80
145·60 = $\frac{A}{2}$ + 2 P + Q × $\frac{2r}{3}$ = { ½ Area of Vertical Section 5, when immersed to the depth of the light-water immersion.

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From these calculations, the following data is given to form a curve of sectional areas for the light displacement of H.M.S. Canopus.

	ft.	in.
To a Draught of Water of Afore	= 14	„ 3
Ditto . . . Aft	= 18	„ 9

Distinguishing Number of the Vertical Sections.	Half Areas of the Vertical Sections. Superficial Feet.	Divisor.	Ordinates for the Curve of Sections.
1	161·57	30	5·38
2	253·11	.	8·437
3	278·88	.	9·29 = fi
4	258·47	.	8·61
5	145·60	.	4·85

From these ordinates the curve of sectional areas, g, h, i, k, m, for the light displacement can be formed for the Canopus, as shown for the similar curve to the Vanguard; the extremes of the curve g and m being the limits of the light-water line, or the points where the light-water line cuts the after edge of the rabbet of the post, and the fore edge of the rabbet of the stem, squared down to the base, ac. To measure the representative area, g, h, i, k, m, g, and thence the zone for the light displacement, join g and i, and m and i; which will divide the area, g, h, i, k, m, g into two triangles, fim and fig, together with the parabolic areas, $ikmi$ and $ihgi$, being the areas contained under the hypothenuses, im, gi, and the curve g, h, i, k, m.

To estimate the numerical values of these areas, we have

fm by measurement = 94·0 ft., and fg = 96·2 feet, and fi by calculation = 9·29 feet.

Whence Area of the Fore Representative Triangle $fim = \frac{fm \times fi}{2} = \frac{94{\cdot}0 \times 9{\cdot}29}{2} = 436{\cdot}63$

Solid under that Area . . . . $= \frac{fm \times fi}{2} \times 30 = \frac{94{\cdot}0 \times 9{\cdot}29}{2} \times 30 = 13098{\cdot}9$

Area of the After Representative Triangle . $fig = \frac{fg \times fi}{2} = \frac{96{\cdot}2 \times 9{\cdot}29}{2} = 446{\cdot}849$

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Solid under that Area $= \frac{fg \times fi}{2} \times 30 = \frac{96{\cdot}2 \times 9{\cdot}29}{2} \times 30 =$ 13405·47 cubic feet of space.

The Hypothenuse $im = \sqrt{\overline{fm}^2 + \overline{fi}^2} = \sqrt{\overline{94}^2 + \overline{9{\cdot}29}^2} =$ $\sqrt{8836 + 86{\cdot}30} = \sqrt{8922{\cdot}3} = 94{\cdot}50$ feet.

Fore Parabolic Area $ikmi = im \times \frac{2}{3}$ of the maximum perpendicular on im.

Zone or Solid under such Area $= im \times \frac{2}{3}$ of the maximum perpendicular on $im \times 30 = im \times \frac{2}{3}$ of $2{\cdot}2 \times 30 = 94{\cdot}5 \times 44 = 4158{\cdot}0$.

The Hypothenuse $gi = \sqrt{fg^2 + fi^2} = \sqrt{\overline{96{\cdot}2}^2 + \overline{9{\cdot}29}^2} =$ $\sqrt{9254{\cdot}44 + 86{\cdot}30} = \sqrt{9340{\cdot}74} = 96{\cdot}6$ feet.

After Parabolic Area $ghig = gi \times \frac{2}{3}$ of the maximum perpendicular on gi.

Zone or Solid under such Area $= gi \times \frac{2}{3}$ of the maximum perpendicular on $gi \times 30 = 96{\cdot}6 \times \frac{2}{3}$ of 2·0 ft. $\times 30 = 3864{\cdot}0$ feet.

From which data the half-light Displacement of Canopus is as follows:—

	Cubic feet of space.
Solid from the Triangle fim	= 13098·9
Ditto . . . fig	= 13405·47
Solid under the Fore Parabolic Area $ikmi$ . . .	= 4158·00
Solid under the After Parabolic Area $ghig$ . .	= 3864·00
	5)34526·37
	7)6905·27
	986·46
	2
	1972·92 = Light Displacement of Canopus in Tons.

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Her Majesty's Ship Vanguard.

	ft.	in.		Tons.
Load Displacement to the Constructor's Draught of Water of Afore	23	0	(P. 97)	= 3293·52
Ditto . . . Aft	24	0		
Light Displacement to the Draught of Water of Afore	16	3	(P. 101)	= 1891·78
Ditto . Aft	18	6		
Difference				1401·74

Giving the Capacity of the Vanguard for carrying Stores, Armament, &c., as equal to 1401·74 tons.

Her Majesty's Ship Canopus.

	ft.	in.		Tons.
Load Displacement to the Constructor's Draught of Water of Afore	22	0	(P. 106)	= 3409·08
Ditto . . . Aft	24	6		
Light Displacement to the Draught of Water of Afore	14	3	(P. 110)	= 1972·92
Ditto . Aft	18	9		
Difference				1436·16

Giving the Capacity of the Canopus for carrying Stores, Armament, &c. as being equal to 1436·16 tons.

	Tons.
Capacity of the Canopus for carrying her Equipments	= 1436·16
Capacity of the Vanguard for carrying her Equipments	= 1401·74
Difference	34·42

From which result it may with justice be asserted that Her Majesty's Ship Vanguard must, under the same stowage as the French Canopus, (a smaller man of war in tonnage,) and with corresponding weights, have been deficient of the required buoyancy by at the least 270 tons, or the immersion of nearly 12 in. bodily.

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PART XVIII.

Application of the Curve of Sectional Areas to the Stowage of the Hold of H. M. Ship Canopus, with Reference to the Directions given at page 21 of this work.

THE area contained between the curve *a*, *b*, *c*, *d*, *e*, (Plate D,) for the load displacement of the Canopus, and the curve *g*, *h*, *i*, *k*, *m*, for the light displacement of the same vessel, will be a representative area of the solid of displacement between those immersions of the ship, or be descriptive of the sum of the weights that will be equivalent to the upward pressure of the water between those two lines of floatation, and each portion of the area will denote the relative buoyancy of the body at that particular division or compartment of it. As an example—

Take the portion contained between the ordinates *f c* and *z w* of the curve of sections for the Canopus, (Plate D,) and the weight that would be equivalent to the upward pressure of the fluid at that compartment of the body may be determined as follows :—

See, also, for the values of *f c*, *f* 1, *z w*, and *z x*, the calculations at pages 104 and 109.

By measurement, *f c* = 14·12 ft., and *f i* = 9·29 ft., and *f c* − *f i* = *c i*, is equal to the ordinate representative of the area *n o p q* of the sheer plan of the Canopus, (Plate D,) or *f c* − *f i* = *c i* by substitution = 14·12 ft. − 9·29 ft. = 4·83 ft.

By measurement, *z w* = 13·0 ft. and *z x* = 8·6 ft., whence *z w* − *z x* = *x w* equals the ordinate representative of the area *r s t v* of the sheer plan (Plate D); or *z w* − *z x* = *x w*, equals by substitution 13·0 ft. − 8·6 ft. = 4·4 ft.;

the difference *c i* = 4·83 ft.
the difference *x w* = 4·4 ft.

Sum = 9·23, which, divided by 2, gives

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4·61 ft. as the mean breadth of the representative area for the compartment *c i w x*; the length between *c i* and *w x*, or the length of the representative area for the compartment *c i w x* = 19·2 ft., whence the area *c i w x*, which is equal to the length multiplied by the breadth, equals 19·2 ft. × 4·61 ft. = 88·512 superficial feet; and the zone or solid to that area = 88·512 × 30 = 2655·36 cubic feet of space, which divided by 35, as the number of cubic feet of space due to a ton of medium water, gives

5)2655·36

7)531·072

75·867 = $\frac{1}{2}$ displacement of the compartment *c i w x* in tons, and 151·73 tons equals the whole displacement due to the portion of the immersed body situated in that compartment between the light and load draught of water. The same reasoning and similar calculations apply to the other portions of the body of the ship.

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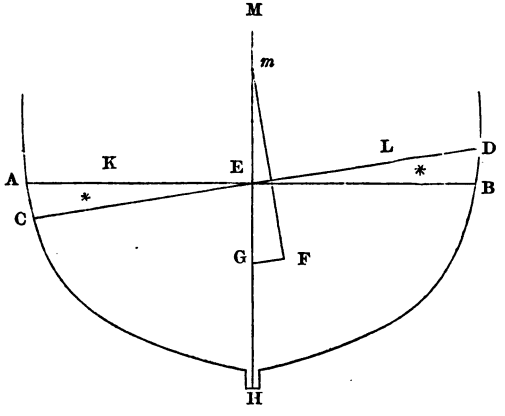
PART XIX.

A Demonstration of the Expression $\frac{2}{3}\int\frac{y^3\,dx}{D}$ as being a Measure of comparative Stability or Stiffness of Floating Bodies, more usually denominated the Height of the Metacentre above the Centre of Gravity of Displacement of the immersed Portion of the Body.

FIG. 16.



IN mechanics, the removal in space of one or more bodies of a system is followed by a corresponding movement in the mass, or that the moment arising from the movement of a portion of the system will be followed by a proportionate moment of the whole. From this fundamental axiom of mechanics the following demonstration of the expression $\frac{2}{3}\int\frac{y^3\,dx}{D}$ has been obtained.

In Fig. 16, A C H B D is the representative vertical and athwartship section of a floating body passing through the centre of gravity G of displacement of the whole immersed body. H M being the middle line of such section, or the common section of the plan A C H B D, with a longitudinal and vertical plane passing through the middle of the body. A B is the line of deepest immersion, or the load-water line.

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Let the section assume the infinitely small inclined position which would make C D coincide with the surface of the water, the form of the section or body being such that the point E will remain unmoved, for the area A L C to be equal to the area D E B; then, if the centre of gravity of the upright immersion, A H B, be supposed to be situated at G, the centre of gravity of the inclined immersion will be at some point F; and if through the point F, when the position of it is determined, a line, F M, be drawn perpendicular to the line C D, the assumed line in which the surface of the water cuts the section, A C H B D, under its inclined position, and this line, F M, be produced to cut the middle line, H M, of the upright position of the section A C H B D in the point M, that point, M, is the point termed the metacentric point to the assumed inclination.

On the supposition that the angle of inclination, A E C or D E B, represented by θ, be very small, the sides A E, E C, E D, and E B of the triangles, A E C, D E B, of the elementary prisms may be considered to be equal, and the centre of gravity of each may be assumed to be respectively $\frac{2}{3}$ of A E and E D from the point E, under which assumption A C or D B, the base of the triangles A E C, B E D, will be equal to A E $\times$ sin. θ,

for E A : A C = r : sin θ, where if r = radius unity,

$$\text{A C} = \frac{\text{A E} \times \text{sin. } \theta}{r} = \text{A E} \times \text{sin. } \theta,$$

and the area A E C or D E B is equal to $\frac{\text{A E} \times \text{A C}}{2}$, which by substituting in it for A C, its value in terms of A E, will become $\frac{\text{A E} \times \text{A E} \times \text{sin. } \theta}{2}$ and if the differential of the length of the elementary Prism = dx, and the displacement be represented by D, and A E = E B = C E = E D = y, then the area A E C, or D E B = $\frac{y^2 \times \text{sin. } \theta}{2}$ and the differential of the prismatic solid = $\frac{y^2 \times \text{sin. } \theta \times dx}{2}$, and the centres of gravity of the triangles

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A E C, D E B are respectively $\frac{2}{3}$ of E A and E D, or $\frac{2}{3}\,y$ from the point E, thence the horizontal moment from E of the differential of the prismatic solid, A E C, will be equal to

$$\frac{y^2 \times \text{sin. } \theta \times dx}{2} \times \frac{2y}{3} = \frac{y^3 \times \text{sin. } \theta \times dx}{3},$$

and the horizontal moment also from E of the differential of the prismatic solid D E B will be equal to $\frac{y^3 \times \text{sin. } \theta \times dx}{3}$; whence $\frac{2}{3}\,y^3 \text{ sin. } \theta \times dx$ will be the sum of the moments of the elementary prisms, immersed and emerged, or the moment that would arise, from the transfer of the elementary prismatic solid, A E C, considered as being concentrated in its centre of gravity, K, to the point, L, the position of the centre of gravity of the prismatic solid, D E B; which moment would produce a corresponding proportional moment in the mass D, or displacement, supposed to be concentrated in its centre of gravity, G, and which was assumed as being equal to G F. Equating these moments, we have

$$\text{D} \times \text{G F} = \tfrac{2}{3} \int y^3 \times \text{sin. } \theta\, dx,$$

$$\text{whence G F} = \tfrac{2}{3} \int \frac{y^3 \times \text{sin. } \theta \times dx}{\text{D}};$$

but m G : G F = radius : sin. θ, the angle G m F being necessarily equal to the angle, A E C, or D E B, and thence $= \theta$ from the lines, G m and F m being severally perpendicular to A B and C D; hence, $m\,\text{G} = \frac{\text{G F}}{\text{sin. } \theta} = \text{G F}$ divided by sin. $\theta = \frac{2}{3} \int \frac{y^3 \times \text{sin. } \theta \times dx}{\text{D}} \times \frac{1}{\text{sin. } \theta} = \frac{2}{3} \int \frac{y^3 \times dx}{\text{D}}$; which determines the height of the metacentric point, m, above the centre of gravity, G, of the displacement.

The expression $\frac{2}{3} \int \frac{y^3\, dx}{\text{D}}$, or the height of the metacentre above the centre of gravity of the displacement, is a measure of the stability, or of the comparative stability of two vessels, under the restriction of the inclination, being evanescent or vanishing; hence forming a practical guide only for the compa-

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rison of vessels whose forms, from inspection, are such as to insure permanent stability. The calculations required to determine the stability of a floating body at finite angles of inclination are much more tedious, and the rules for them involve a larger portion of mathematical knowledge than what a novice may possess; but as these calculations test an important property of a naval construction; the equality of the volumes of immersion and emersion of the body under finite or practical inclinations, it would be better, in this rudimentary work, to have done some little beyond the boy's "first book," than to leave this element without investigation and deduction, the more especially so, from a knowledge, by past proofs, that an erroneous conception of this elementary feature of a naval construction, is too well calculated to involve the naval empirical constructor in errors, that would render the ships designed by him when considered as floating batteries very inefficient, from their uneasy movements in a sea-way, which uneasiness would be alone produced by a disregard of the effects that arise to the construction by the inequalities of the volumes of immersion and emersion. Being anxious to be clear in the definition of this matter, let it be understood, that the volume of immersion means that part of the body of the ship immediately above the surface of the water before inclination, and which is forced into the fluid by the inclining power of the sails; and that the volume of emersion, is that portion of the body of the ship which leaves the water on the inclination being given to her. With these points defined, and under the consideration that the vessel moves round her common centre of gravity, not as a fixed point but a moveable one, and that the ship, while under canvas and the consequent inclination, cannot, from such inclination, be made to increase her displacement or total weight, the actual stabilities of the two ships, Canopus and Vanguard, will be deduced from the expression and form of calculations that follow.

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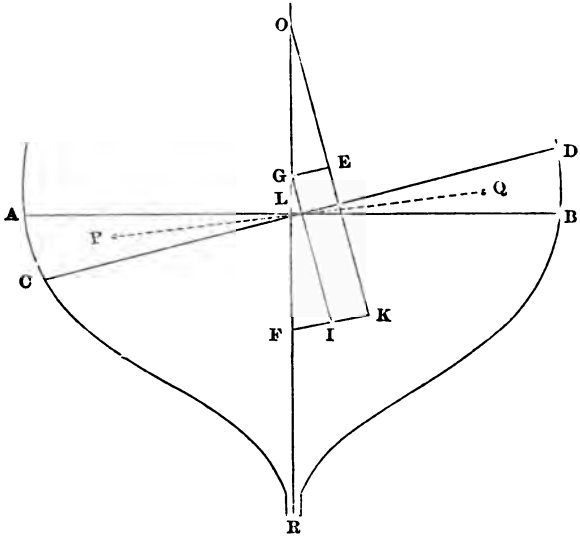
PART XX.

Investigation of a General Expression for the Stability of a Ship at Finite Angles of Inclination, and the Application of the Results to calculating the Stability of H. M. S. Vanguard and Canopus, at an Angle of Seven Degrees.

Stability at Finite Angles of Inclination.

Fig. 17.



Let A R B be the midship section of a ship immersed to the line A B, and let the ship be so inclined as to make the line C D the upper line of immersion or the surface of the water, L being the point of intersection of the lines A B and C D; this assumed inclination of the ship, which is represented by the midship section C R D, will cause an alteration

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in the immersed volume A R B, which will, under the inclination, become C R D, and the volume represented by C R D, will be equal to that represented by A R B, the weight of the ship being the same under both positions. By this movement the prismatic solid, represented by A L C, which call P, will be emerged from the displacement A R B, and the prismatic solid D L B, which call Q, will be immersed to form the displacement C R D; under which considerations the form of the ship, immediately above and below the surface of the water, A B, when the vessel is upright, will materially affect the motion of the ship in a sea-way; for if the portion of the body which is immersed by inclination, as represented by D L B, becomes, from the form of the sides, larger than A L C, which is emerged, the whole body or displacement remaining the same, which it necessarily must, the weights being unaltered, it follows that there must be a constant rising of the body during the inclination produced by rolling, and a similar falling on her return to the upright position; and further, if the centre of gravity of these necessarily equal portions, viz., the volumes, immersions and emersions, should not be in the same vertical plane with each other, further defect would arise, viz., that on the inclination of the vessel, the head of her would be elevated or depressed, according as the centre of gravity of the immersed prism was abaft or before the centre of gravity of the emersed prism; the question then resolving itself into the case of increased or decreased immersions about the longitudinal axis of the vessel. Assuming the solids of immersion and emersion to be represented by Q and P, and that they be considered as concentrated in their respective centres of gravity Q and P, let the horizontal distance between the centres Q and P be taken as (b): then the moment that will arise, from the change of the immersed body A R B, to that of the immersed body C R D, which would cause the transfer of the prism A L C, concentrated in P, to a similar and equal prism D L B, concentrated at Q, will be denoted by the product of P or Q into the distance P Q; or, by

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substitution, P × PQ will be equal to δ × P, which moment of the part A L C of the immersed body will produce an equivalent movement on the whole mass or solid A R B.

Let G (figure annexed) represent the position of the centre of gravity of the whole mass, or the ship with all her weights; F the position of the centre of gravity of the displacement, represented by A R B, the ship being upright; K the position of the centre of gravity of displacement, when the vessel is so inclined that the surface of the water coincides with C D, or when C R D represents the immersed body; from K draw K O perpendicular to C D, meeting R O, the vertical middle line of the body in some point O, from which construction of the figure the line K O on the proposed inclination of the ship would become vertical from the points E and F, the assumed positions of the centres of gravity of the ship and her displacement; draw the lines G E and F H perpendicular to K O, and thence parallel to C D, or the surface of the water when the ship is inclined, and through G draw G I parallel to K O, cutting F H in the point I. Upon the ship taking the inclined position C R D, the point K becomes the assumed situation of the centre of gravity of the immersed body C R D, or the displacement, and the upward pressure of the water equivalent in force to the weight of the displacement represented by D may be supposed to act in the vertical line K O, to restore the ship to the upright position A R B, round the axis of the rotation G, the centre of gravity of the vessel; which effort can be measured by the property of the lever, by drawing a perpendicular from the centre of motion, or G, to the direction of the force K O, which by the construction of the figure is G E, whence the effort exerted by the displacement D, to restore the ship to the upright position A R B, will be represented by the product arising from multiplying the displacement by the perpendicular from the centre of motion on K O, the direction of the restoring force; or the effort of stability = displacement multiplied by G E = D × G E. But by the construction of the figure, D ×

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G E = D × I H, G I H E being a parallelogram or the effort of stability = D × I H = D × $\overline{\text{F H} - \text{F I}}$ as I H = $\overline{\text{F H} - \text{F I}}$, whence effort of stability = D × G E = D × $\overline{\text{F H} - \text{F I}}$, in the which O K has been assumed as the vertical direction of the upward pressure of the fluid passing through the centre of gravity of displacement. After the inclination of the vessel, it follows, that D × F H will be equal to the horizontal moment of the displacement, produced by the change of position of the immersion A R B to that of C R D; and it is thence equal to the horizontal moment expressed by b P, and the effort to restore the vessel to the upright position, or the moment of stability as it is termed, will thence give the equation of D × G E = D × $\overline{\text{F H} - \text{F I}}$ or, by substitution,

= D × F H − D × F I

= b P − D × F I, and the sine of the angle of inclination A L C, or D L B, being denoted by s; and G F the distance between the centres of gravity of the ship, and the displacement being expressed by d, the value of F I may be determined, as F G : F I = rad. : s whence taking rad. as unity F G : F I = 1 : s, or F I = F G × s = d s, and the expression for the stability under the inclination of the angle A L C, or D L B, becomes D × G E = b P − D d s, whence $\text{G E} = \frac{b\text{P}}{\text{D}} - d\,s$.

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PART XXI.

The Volumes of Immersion and Emersion of H. M. Ships Vanguard and Canopus, calculated to an Angle of 7°.—Concluding Remarks and Observations.

The Volumes of Immersion and Emersion of H. M. Ship Vanguard, when inclined to an Angle of Seven Degrees from the upright.—Plate F.

Immersion.

Vertical Section 2.

Half-breadth . .	= 25·9
Perpendicular . .	= 2
Divided by 2)	51·8
Area of Triangle of Immersion	= 25·9 ft.

Vertical Section 3.

Half-breadth . .	= 28·4
Perpendicular . .	= 2·1
	284
	568
Divided by 2)	59·64
Area of Triangle of Immersion	= 29·82 ft.

Emersion.

Vertical Section 2.

Half-breadth . .	= 25·9
Perpendicular . .	= 1·9
	2331
	259
Divided by 2)	49·21
Area of Triangle of Emersion	= 24·60 ft.

Vertical Section 3.

Half-breadth . .	= 28·2
Perpendicular . .	= 2·05
	1410
	5640
Divided by 2)	57·810
Area of Triangle of Emersion	= 28·905 ft.

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IMMERSION.

Vertical Section 4.

Half-breadth . . = 28·4
Perpendicular . . = 2·16

1704
284
568

Divided by 2)61·344

Area of Triangle of Immersion } = 30·67 ft.

Vertical Section 5.

Half-breadth . . = 27·8
Perpendicular . . = 2·1

278
556

Divided by 2)58·38

Area of Triangle of Immersion } = 29·19 ft.

Vertical Section 6.

Half-breadth . . = 25·6
Perpendicular . . = 2·0

Divided by 2)51·20

Area of Triangle of Immersion } = 25·60 ft.

EMERSION.

Vertical Section 4.

Half-breadth . . = 28·2
Perpendicular . . = 2·15

1410
282
564

Divided by 2)60·630

Area of Triangle of Emersion } = 30·315 ft.

Vertical Section 5.

Half-breadth . . = 27·4
Perpendicular . . = 1·8

2192
274

Divided by 2)49·32

Area of Triangle of Emersion } = 24·66 ft.

Vertical Section 6.

Half-breadth . . = 24·0
Perpendicular . . = 1·7

168
24

Divided by 2)40·8

Area of Triangle of Emersion } = 20·4 ft.

The triangular portions at the extremities of the load-water section consequent upon the inclination give the contents of ·1 of a foot for each, and thus seven areas are formed for esti-

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mating the solids of immersion and emersion to an angle of seven degrees.

VANGUARD.

Immersion to Seven Degrees Inclination.

Distinguishing Number of the Areas.	Contents of the Areas.	Multipliers by the First Rule.	Multiples for the Solid.
1	·10	½	·05
2	25·90	2	51·80
3	29·82	1	29·82
4	30·67	2	61·34
5	29·19	1	29·19
6	25·60	2	51·20
7	·10	½	·05
			223·45

$223{\cdot}45 = \left\{\frac{A}{2} + 2P + Q\right.$ of the formula.

The distance between the areas is equal to 31·0 feet, whence $r = 31$ feet, which, substituted in the formula for the solid, $= \frac{A}{2} + 2P + Q \times \frac{2r}{3}$, to sum these areas, gives $223{\cdot}45 \times \frac{62}{3} = \frac{13853{\cdot}9}{3} = 4617{\cdot}96$ cubic feet for the contents of the solid of immersion, according to the lines of inclination on the draught when the ship is inclined to an angle of seven degrees from the upright position.

VANGUARD.

Emersion to Seven Degrees Inclination.

Distinguishing Number of the Areas.	Contents of the Areas.	Multipliers by the First Rule.	Multiples for the Solid.
1	·10	½	·05
2	24·60	2	49·20
3	28·90	1	28·90
4	30·31	2	60·62
5	24·66	1	24·66
6	20·40	2	40·80
7	·10	½	·05
			204·28

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The distance between the areas as before for the immersion is equal to 31·0 feet, whence $r = 31{\cdot}0$ feet, and the formula for the solid $= \left\{\frac{A}{2} + 2P + Q\right\} \times \frac{2r}{3}$ gives $204{\cdot}28 \times \frac{62}{3} = \frac{12665{\cdot}36}{3} = 4221{\cdot}786$ cubic feet for the contents of the solid emerged, when the ship is inclined to an angle of seven degrees from the upright position, according to the inclined lines on the drawing, Plate F. From these calculations, viz.—

	Cubic feet.
The solid of immersion to 7°	= 4617·96
The solid of emersion „	= 4221·78
Whence the difference	= 396·18

or that the total displacement would under such an inclination be increased by 396·18 cubic feet; but as the total volume immersed remains the same, and the ship does not move round a fixed axis, it follows, that the tendency to increase the volume immersed by the excess of the immersed solid over the emerged, or the solid denoted by 396·18 cubic feet, will cause a rising in the whole mass, and in a sea-way where the rolling is made up of a succession of these inclinations, the reverse or a falling of the mass will take place, each time that the ship is passing to the upright position; the inclination having been assumed at 7°, the difference of the solids is nearly at the minimum, and at higher angles of rolling this effect would be found to be of a much greater magnitude, and the uneasy motion of the Vanguard in a sea-way may with justice be partly attributed to a disregard of this necessary adjustment of the form of the ship, immediately above and below the seat of water or the load-water line.

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The Volumes of Immersion and Emersion of H. M. Ship Canopus, when inclined to an Angle of Seven Degrees from the upright.—Plate F.

Immersion.

Vertical Section 2.

Half-breadth . .	= 24·6
Perpendicular . .	= 1·9
	2214
	246
Divided by 2	46·74
Area of Triangle of Immersion	= 23·37 ft.

Vertical Section 3.

Half-breadth . .	= 26·0
Perpendicular . .	= 2·0
Divided by 2	52·0
Area of Triangle of Immersion	= 26·0 ft.

Vertical Section 4.

Half-breadth . .	= 26·3
Perpendicular . .	= 2·1
	263
	526
Divided by 2	55·23
Area of Triangle of Immersion	= 27·61 ft.

Emersion.

Vertical Section 2.

Half-breadth . .	= 24·6
Perpendicular . .	= 1·8
	1968
	246
Divided by 2	44·28
Area of Triangle of Emersion	= 22·14 ft.

Vertical Section 3.

Half-breadth . .	= 26·0
Perpendicular . .	= 1·9
	234
	26
Divided by 2	49·4
Area of Triangle of Emersion	= 24·7 ft.

Vertical Section 4.

Half-breadth . .	= 26·3
Perpendicular . .	= 2.1
	263
	526
Divided by 2	55·23
Area of Triangle of Emersion	= 27·61 ft.

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Immersion.

Vertical Section 5.

Half-breadth . .	= 24·6
Perpendicular . .	= 1·9
	2214
	246
Divided by 2	46·74
Area of Triangle of Immersion	= 23·37 ft.

Vertical Section 6.

Half-breadth . .	= 23·8
Perpendicular . .	= 1·8
	1904
	238
Divided by 2	42·84
Area of Triangle of Immersion	= 21·42 ft.

Emersion.

Vertical Section 5.

Half-breadth . .	= 24·6
Perpendicular . .	= 1·9
	2214
	246
Divided by 2	46·74
Area of Triangle of Emersion	= 23·37 ft.

Vertical Section 6.

Half-breadth . .	= 23·8
Perpendicular . .	= 1·8
	1904
	238
Divided 2	42·84
Area of Triangle of Emersion	= 21·42 ft.

The triangular portions at the extremities of the load-water section, as in the Vanguard, on calculation, give ·1 of a foot for each when, as in the case of that ship, seven areas have been calculated; which areas, when placed in Sterling's Rule for the estimating a solid, will give the solids of immersion and emersion to an angle of seven degrees.

Canopus.

Immersion to Seven Degrees Inclination.

Distinguishing Number of the Areas.	Contents of the Areas.	Multipliers by the First Rule.	Multiples for the Solid.
1	·10	½	·05
2	23·37	2	46·74
3	26·00	1	26·00
4	27·61	2	55·22
5	23·37	1	23·37
6	21·42	2	42·84
7	·10	½	·05
			194·27 = $\frac{A}{2}$ + 2P + Q

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and the distance between the areas is equal to 32·5 feet $= r$; which values being substituted in the formula for the solid of $\frac{A}{2} + 2P + Q \times \frac{2r}{3}$ gives 194·27 feet $\times \frac{65·0}{3} = \frac{12627·55}{3} =$ 4209·18 cubic feet for the contents of the solid of immersion, according to the lines of inclination on the draught when the ship is inclined to an angle of seven degrees from the upright position.

Canopus.

Emersion to Seven Degrees Inclination.

Distinguishing Number of the Areas.	Contents of the Areas.	Multipliers by the First Rule.	Multiples for the Solid.
1	0·10	½	·05
2	22·14	2	44·28
3	24·70	1	24·70
4	27·61	2	55·22
5	23·37	1	23·37
6	21·42	2	42·84
7	·10	½	·05
			190·51 $= \frac{A}{2} + 2P + Q$

the distance between the areas as before $= 32·5$ feet $= r$; whence the solid of emersion $= \frac{A}{2} + 2P + Q \times \frac{2r}{3} = 190·51 \times \frac{65}{3} = \frac{12383·15}{3} = 4127·71$ cubic feet of space.

From which calculations, viz.—

The solid of immerson to seven degrees	= 4209·18	Cubic feet.
The solid of emersion . . .	= 4127·71	„
Difference	= 81·47	Cubic feet.

The difference that was found between the solids of immersion and emersion in H. M. Ship Vanguard, under the same inclination, seven degrees, was 396·18 feet, or nearly five times

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the amount of that in the Canopus, and thence is developed one cause of the easier motions of the latter ship in a seaway.

The positions of the centres of gravity of the volumes immersed and emerged, with respect to the longitudinal axes of the ship, may be determined by the areas already calculated, the moments of them may be obtained as described for the centre of gravity of displacement, and summed by Sterling's Rules, (page 43); and should these centres not be found in the same vertical athwartship plane, there will ensue on inclination, a depression or elevation of the bow, according as the position of the centre of gravity of the immersions of the body is abaft or before that of the emersions, and it need not be dwelt much upon, when their being in the same vertical and athwartship plane is insisted on.

The solids of immersion and emersion having thus been calculated and contrasted, an adjustment of the form must take place, or the position of the point S, Plate F, where the inclined line denoting the surface of the water on inclination cuts the line denoting the upright position of the ship, must be changed until these volumes become equal.

When this has been effected, find the distance of the centre of gravity of each of the triangles of immersion, as S v r, from the point S, by bisecting r v in w, joining S and w, and taking $\frac{2}{3}$ of s w from S or S q, giving the point q as the centre of gravity of S r v, the moment of the area S r v from S will thence be equal to S r v $\times$ S q; and if the moment of each triangle of immersion from the point S be calculated in a similar manner, and these results be placed in the rule as described (p. 43) for the displacement, the multiple of the sum of the moments of the immersed areas from the point S will be determined; and this result, being divided by the corresponding multiple for the solid, will give the distance of the centre of gravity of the immersions from S.

The centre of gravity of the emerged portion of the body

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may be obtained in the same way, and the horizontal distance between these centres of immersion and emersion will give the portion b of the expression, for the measures of stability, (b I — D $d s$,) as being the horizontal distance between the centres of gravity of the two solids; and half the sum of the solids of immersion and emersion will be equal to I of the same expression, whence the product of the horizontal distance that the centres of gravity of immersion and emersion are apart and the half sum of the solids will give b I, or the positive part of the expression, for the moment of stability; of the negative part of the expression, (D $d s$,) D is known from previous calculations, being the total volume immersed; s = sine of inclination also given, and d must be assumed, being the distance between the centre of gravity of displacement which is known, and the centre of the ship which can only be approximated to.*

The value of the positive part of the expression, $b i$, being reduced by the value of the negative part of the same, D $d s$ will give the value of the expression for the measure of the stability at the given angle of inclination. These calculations would have been continued out, but were considered lengthy for this small work; enough has been done, it is trusted, to enable the student to follow out the system, as the practical operations are strictly similar to those used for the development of the elements of the displacement.

In calculating the displacement from the building draught, the displacement to the outside of the plank will be closely approximated to; if the moulded displacement be calculated, from the drawing to a draught water, less than the proposed load immersion by the thickness of the plank of the bottom, as the result or moulded displacement will form the basis of a proportion to give the displacement to the outside of the

* By the ship is meant the whole mass, viz., Hull, Stores, and Equipments.

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plank, as similar solids are to each other as the cubes of any one of their dimensions; hence,

Moulded displacement will be to the required displacement as the cube of the moulded breadth : to the cube of the breadth with the plank on; in which proportion three terms are known whence the fourth can be easily determined.

Much might be advanced with reference to the proportion that should be maintained between the lengths and breadths of ships, but in this foundation as it were of the superstructure, there are so many variations to be deduced from practice, all equally good, that it would be highly empirical, and still more unscientific, if it were attempted to set up a standard measure in this matter, but one point in forming a construction for war purposes should never be lost sight of by the naval architect —that the ship of war is intended as a floating battery, and that for efficiency the platform should afford unconfined space for the required movements of the guns mounted on it. With this fundamental axiom in view, the armament of the ship should be the first consideration, and the platform or deck for the evolutions of that armament should be described under the maximum positions of recoil and training of the guns that the naval artillerist may deem necessary for the full effect of the battery. Then let the naval architect give to this platform—for an effective training and fighting battery—a substratum or displacement that will ensure to it the power of floating at the required height above the line of deepest immersion or the load-water line.

The form to be given to that displacement, or to the ship, Practice and its adjunct, Theory, (one based on a well-digested system of practical results and facts,) must be made the means by which the desirable end may be accomplished—the perfecting of a "System of Naval Construction."

The calculations on the immersed portions of a ship have been given in detail, and the young naval architect has been thence furnished with the means of testing the ships of the former

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and the present times, by comparing the essential elements of them, under a form that is novel and comprehensive. There has been no attempt in this rudimentary work to lay down laws for the construction of ships, no empirical stalking-horse has been set forth on a subject that requires the deepest thought and the greatest care, to prevent great and unnecessary National expenditure, and to avert the vexatious disappointments, which must ever attend on the faulty construction of our ships of war. And, in conclusion, should this outline of the most important branch of knowledge to Great Britain be the forerunner of larger and more useful works on the same subject, it is only to be hoped that the present one may be found a safe and useful auxiliary to them.

FINIS.

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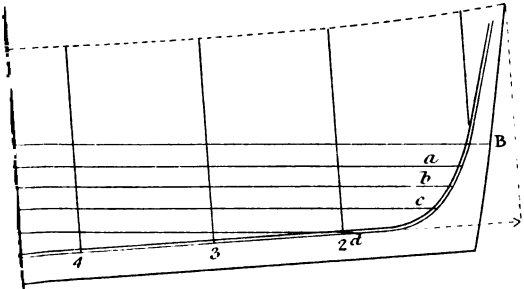
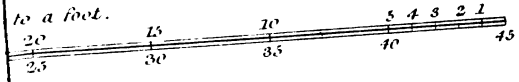
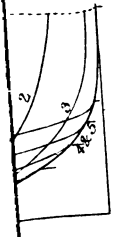
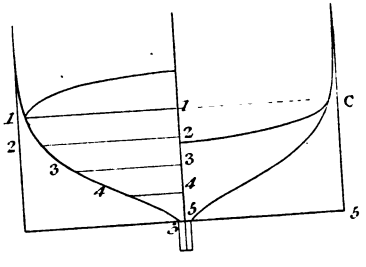
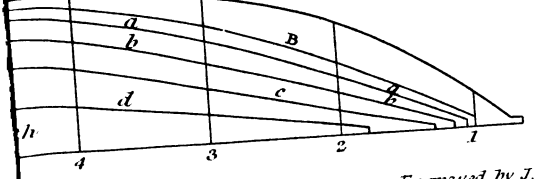




Section at 3.







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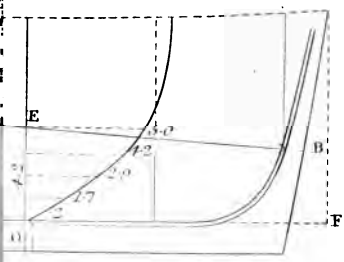

A B = *44 feet*
F G = *44* ..
F I = *22* ..
I G = *22* ..
Q G = *22.37* ..
F Q = *22.37* ..

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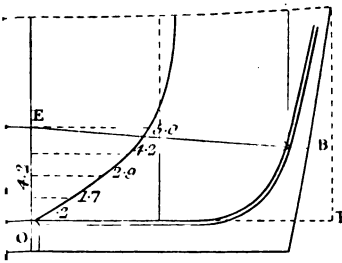

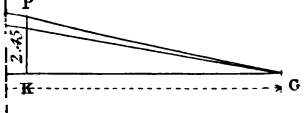

A B = *44 feet*
F G = *44* "
F I = *22* "
I G = *22*
Q G = *22.37*
F Q = *22.37*

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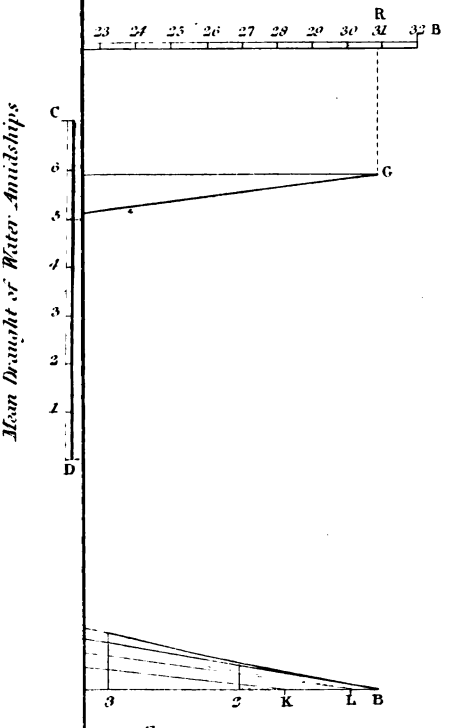
Plate C.

Scale 5/16 of an Inch to One Ton.



to a Foot

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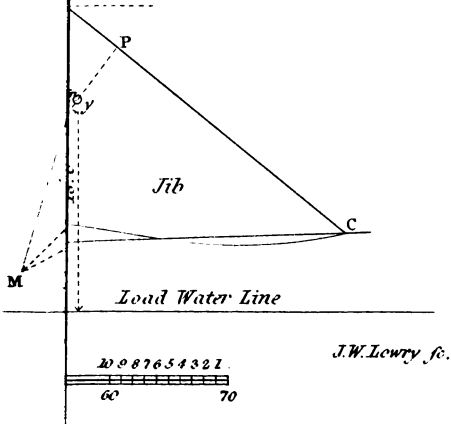
F SAILS.

Fig. 16.



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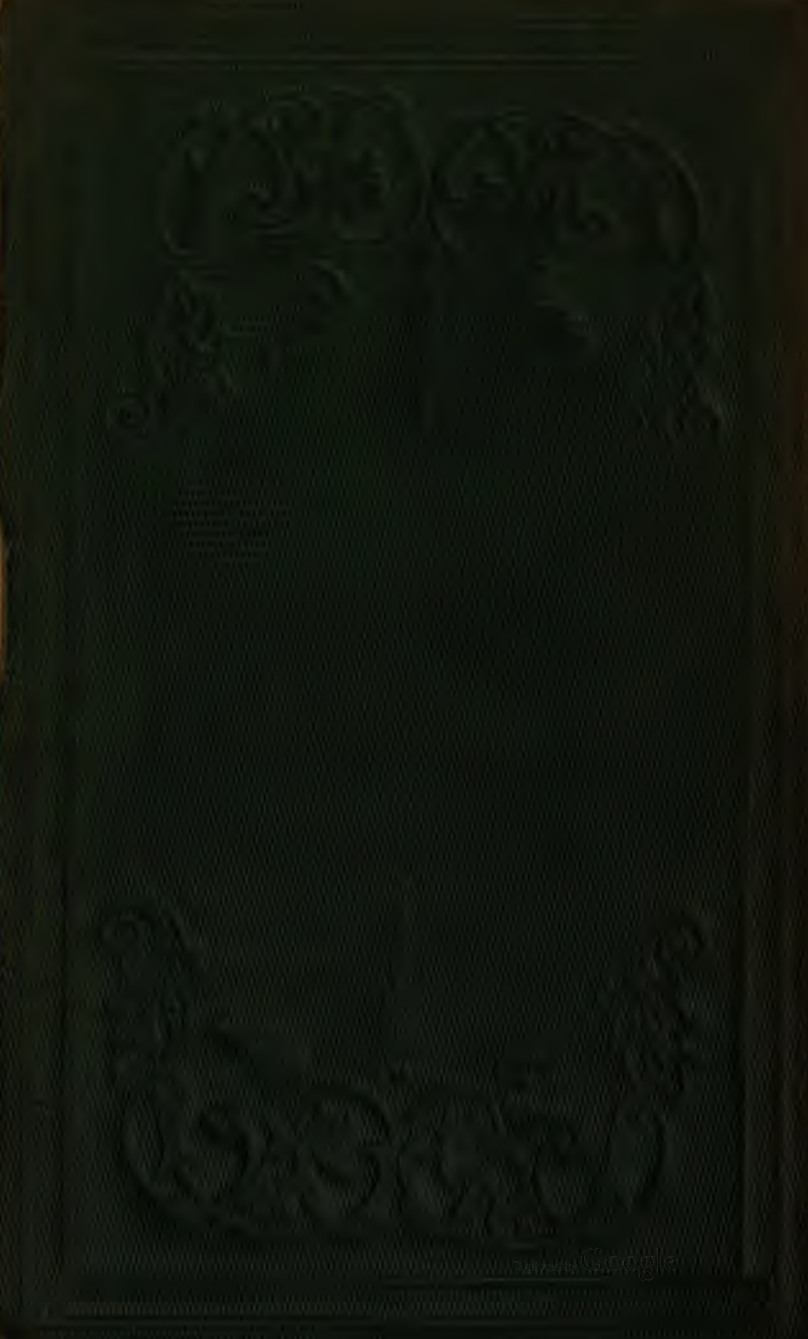
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